ASSESSMENT OF THE ENERGY SAVING MEASURES USED IN THE ER-I CONSERVATION/SOLAR RESEARCH HOUSE

September 1983

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Innovative Housing Grants Program

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Introduction

The research house, ER-1, was built to demonstrate and measure the results of a variety of energy saving measures integrated within a standard house. These energy saving measures incorporate passive solar energy, supplementary wood heating and super insulation levels coupled with energy recovery, storage and distribution systems.

Monitoring Program

A computerized program was developed to monitor air, water and soil temperatures, solar energy gains, water, electricity, wood consumption, and relative humidity.

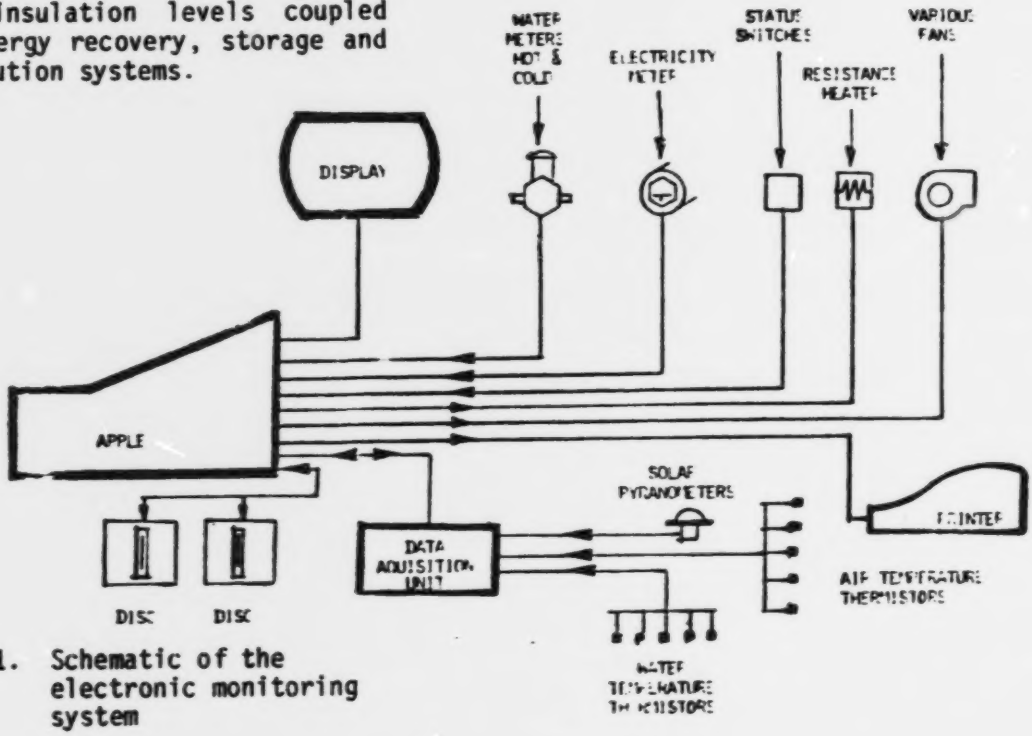

Figure 1. Schematic of the electronic monitoring system

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Building Envelope

The above grade walls have an RSI value of 5.5 (R-31) and the ceilings have an RSI value of 7.9 (R-44). The 135 micrometer (6 mil) poly vapour barrier was sealed with accoustic caulking resulting in an air infiltration rate of 0.06 air changes per hour. With the use of triple glazing the calculated heat loss at - 37C was 6500 watts.

Solar Energy System

The solar energy gain was electronically monitored with sensors that determined incoming solar energy on various areas of the house. The design analysis estimated that approximately 60% of the annual supplemental space heating requirements would be supplied by solar energy.

Triple Glazing

Triple-glazed windows were assessed for effectiveness in reducing condensation and night time window heat loss. Condensation and some frosting did occur on the lower edges of the windows at extreme temperatures. Considering the alternatives, triple glazing was considered the most practical window treatment.

Fresh Air Heat Exchanger

A fresh air heat exchanger was installed to control humidity levels, enhance indoor air quality and to recover heat from waste house air. The unit worked well, recovering approximately 70% of the heat from waste air and it did not frost up even in severe weather conditions.

Heat Storage Bank

The practical aspects of a short term heat storage bank were studied. The heat storage bank consisted of 447 trays of Glauber's salt phase change material, located in an insulated compartment. Air from the ceiling of the house was directed through the stacked trays for heat removal (cooling mode) or addition (heating mode). The cooling mode of the heat bank worked well. The storage of heat produced uncertain results.

Use of the Wood Burning Stove

A wood burning stove was installed to function as a primary wintertime heat source. Actual savings by burning wood from the site cleared for the ER-1 house on space heating costs were $240 during the first year compared to the cost of electric heat. While operation of the stove was not difficult, it required extra personal effort.

Conclusions

The costs, benefits and inconveniences of the energy-saving measures were assessed and compared. The total net costs were $3400. The first year return on investment was 25%, resulting in a simple payback period of four years. The net contribution of the energy conserving measures provides 59% of the total heating requirements for the ER-1 house.

FOREWORD

This study was made possible with funding provided by the Innovative Housing Grants Program of the Alberta Department of Housing. Originally conceived in 1978, the Program is intended to encourage, sponsor, and assist research and development in the fields of housing, site and subdivision design, energy conservation, site servicing and urban development. Generally, the aims of research funded by the Innovative Housing Grants Program are to reduce housing costs, increase the supply of appropriate housing or improve the utility or performance of dwelling units or subdivisions.

The main purpose of funding these studies is to examine the current issues in the field of housing and to develop innovations which offer improvements. Comments and suggestions regarding the information contained in these reports are welcome.

Innovative ideas come from a wide variety of applicants such as builders, developers, consulting firms, industry associations, municipal governments, educational institutions, non-profit groups and individuals. As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied.

Where possible the Department encourages the dissemination of study results under a standard cover and in a uniform format. This study, Assessment of the Energy Saving Measures Used in the ER-1 Conservation/Solar Research House, was completed in June 1983 and subsequently released under a different cover.

Please send comments and suggestions or requests for further information to:

Innovative Housing Grants Program
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EXECUTIVE SUMMARY

In recent years, people have become more aware of energy, its cost and limitations, and of their dependence on energy for their standard of living. In response to the demand of homeowners for assistance in reducing the high energy costs of their homes, many energy-saving products and designs began to appear. To gain experience with some of these products and designs, and to tests their practical value in Alberta, G. M. Rekken and Associates built a solar/conservation research house, ER-1, near Stony Plain, Alberta.

This report is the result of a grant let by the Innovative Housing Grants Program of Alberta Housing to assist in the monitoring and study of the energy-saving measures incorporated into ER-1.

The report provides an overview of the house, its aesthetic features and energy-saving measures, and an overview of the program which monitors its performance. The performance and practical aspects of the systems for energy managment, supply, storage, and recovery are assessed. General results for each of the systems are presented, along with an overall economic assessment of the energy-saving measures.

The assessment shows that the most important factors in home heating are the basic energy conservation techniques. High insulation levels, and air-tightness on ER-1 provide 59% of the savings. Secondly, solar energy can provide signficant fractions of the required supplemental space heating, which on ER-1 amount to 62% annually.

The investment in energy-saving measures on ER-1 was $3400 for space heating. The net value of the benefits provided a 25% rate-of-return in the first year.

It is hoped that this information will be of use to government agencies, the housing industry and home owners, and help to provide some of the answers they have been seeking regarding energy saving options and the benefits of energy conservation and solar energy.

The views and conclusions expressed and the recommendations made are entirely those of the authors and should not be construed as expressing the opinions of Alberta Department of Housing.

ASSESSMENT OF THE ENERGY SAVING MEASURES USED IN THE ER-1 SOLAR CONSERVATION RESEARCH HOUSE

INTRODUCTION

Driven by higher costs and aided by modern products, techniques, and computerized design methods, many new homes are now being built in Alberta incorporating measures which save energy. To assist in evaluating the performance of these measures, G. M. Rekken and Associates established an energy research house, ER-1, near Stony Plain in 1981.

This report describes the assessment of the energy saving measures in ER-1. The assessment was commissioned by the Innovative Housing Grants Program of Alberta Department of Housing. At the time of commissioning, several areas were identified as worthy of special study:

- the super-insulation system,
- the solar energy gains,
- the heat storage bank,
- the triple-glazed windows,
- the fresh-air heat exchanger,
- the grey-water heat exchanger,
- the wood burning stove,
- the air exchange requirements.

Each of the study areas was configured as an individual research project. In this report, the projects are discussed in separate chapters under the headings:

1. SUMMARY
2. BACKGROUND
3. SYSTEM DESIGN
4. ASSESSMENT TECHNIQUES
5. PRELIMINARY RESULTS AND DISCUSSION

The projects were assessed technically by monitoring their energy performance with an electronic data acquisition system, while their aesthetic and comfort factors were judged by observation.

The complete program of research has not been fully carried out at this time. The program will involve continuing measurement, data collection and data evaluation and although we have a reasonable degree of confidence in the document at this time, the report is subject to revision.

The views and conclusions expressed and the recommendations made are entirely those of the authors and should not be construed as expressing the opinions of Alberta Department of Housing.

CHAPTER 1. OVERVIEW OF ER-1

1. SUMMARY

The research house, ER-1, was built to demonstrate energy saving measures integrated within a standard house setting. Architectural features of the house include clerestory windows, cathedral ceilings, a solarium, and a spiral stair. Energy saving strategies incorporate solar energy, supplementary wood heating, and super-insulation levels coupled with an energy recovery, storage, and distribution system.

2. BACKGROUND

In recent years, people have become more aware of energy, its costs and limitations, and of their dependence on energy for their standard of living. In response to the demand of homeowners for assistance in reducing the high energy costs of their homes, many energy-saving products and designs began to appear. To gain experience with some of these products and designs, and to test their practical value in Alberta, G. M. Rekken and Associates established a solar/conservation research house, ER-1, near Stony Plain, Alberta.

ER-1 was designed and built by G. M. Rekken and Associates, an Edmonton engineering consulting company, with design assistance provided by solar research engineer, D. Gordon Howell.

3. HOUSE DESIGN

A. Aesthetic Features

The house is set into the side of a small south facing hill, surrounded by a poplar forest, (Figure 1.1). The house has 169 m2 of total living area on two levels. A loft and hallway on the upper level open to the dining and living rooms below. Appendix A details the elevations and floor layouts.

A spiral stair extends between the two floors. The enlarged column at its centre serves as a heat recirculating duct, (Figure 1.2). An air-tight wood stove in a fireplace setting is on one wall of the living room.

The front door opens from a protected porch into an air-lock entrance foyer.

In addition to being a living space, a solarium provides extra heat to the house in the spring and autumn and a room to care for plants.

Figure 1.1 South elevation

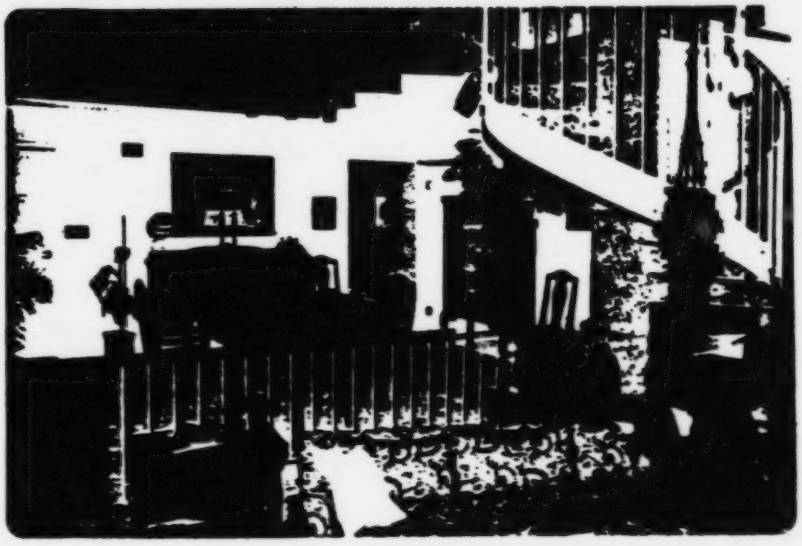

Figure 1.2 Dining room showing central spiral stair and heat recirculating pipe

The north side of the main floor is set below grade, and includes the laundry room, guest bathroom, and workshop.

The kitchen has standard appliances, (Figure 1.3). The ENERGUIDE directory of appliances published by Consumer and Corporate Affairs Canada was used to help choose the appliances in order to be assured of controlled energy usage in the kitchen. A recirculating type range hood was installed to reduce uncontrolled air infiltration.

Figure 1.3 Kitchen

The upper floor contains the loft, two bedrooms, and main bathroom. South facing clerestory windows with cathedral ceilings provide the area with natural daylighting, (Figure 1.4).

The foundation floor of the house is a concrete slab 2.6 metres below grade on the north and 0.6 m on the south. Below grade wall construction is of preserved 2x8 studs.

A 1.2 m high basement/crawl space with a concrete floor was constructed under one third of the house. A crawl space was built to reduce the major construction and heating costs otherwise associated with full basements. The mechanical components of ER-1 are located here. The crawl space and a cold storage room are entered through an attached garage.

Figure 1.4 Master bedroom with clerestory windows

B. Energy Features

ER-1 was built with Rsi 5.5 (R31) wall and Rsi 7.9 (R45) ceiling insulation. A sealed 135 micrometre polyethylene air/vapour barrier was installed to eliminate cold drafts and reduce the loss of air moisture. Triple-glazing was used on the windows to reduce winter heat loss and moisture condensation, and summer heat gain. The major portion of the 20.6 m2 of total window glazing area was placed on the south side of the house to take advantage of energy from the sun.

The heat loss rate of the house at -37 C is 6500 W (the equivalent of four toasters). Because of the very low energy requirements of ER-1, it was felt that heating with natural gas would be a poor use of financial resources. As a result, the natural gas furnace, flue, chimney framing, connections, natural gas supply line and monthly service charges were

eliminated. In place of this, a small electric element heater was installed in an air recirculation duct. Also eliminated were a sealed, insulated furnace room as is found in some low energy houses, and the furnace combustion air intake required by the Building Code.

The air-tight wood burning stove was installed instead of a fireplace, to provide any supplementary space heat required (see also Chapter 9). For heating requirements during extended holidays away from the house in the winter, the thermostatically controlled electric heating element can be used.

Domestic water is pre-heated by a grey-water heat exchanger and a passive solar water heater. If necessary the water is given a final temperature boost by a standard electric water heater (see Chapter 8). The supply water passes through these three devices under normal house water pressure (without any additional pumps or controls being required).

A fresh-air heat exchanger controls air ventilation and humidity. It is operated automatically by a humidistat in the dining room, and interlocked to the clothes dryer and bathroom fans (see also Chapter 7).

A heat storage bank was installed for testing purposes, and to provide short term heat storage. It consists of 447 phase change trays containing Glauber's salt or sodium sulphate decahydrate. The salt changes phase from a liquid to a solid at 20 C when releasing energy, and the reverse when storing energy (see also Chapter 5).

Air is recirculated throughout the house by a destratifying air recirculating system. Warm air is drawn from the top of the house down the pipe forming the spiral stair, through the heat storage bank, and back through ducts. Due to the low energy requirements of the house, the number of ducts in ER-1 was reduced to seven from the seventeen required by a standard house of similar dimensions.

4. ASSESSMENT TECHNIQUES

Feedback on the performance of a design or a project is often missing. In recent years, this has become a particular concern in the energy field. To provide feedback on ER-1 and its systems, the house was installed with a means for evaluating its performance in light of Alberta's energy pricing structure, northern climate and solar energy levels.

It is recognized that aesthetic and comfort factors, in addition to performance, are important in the acceptance of new energy systems by the public. A family, with a knowledge of residential energy systems, lived in the house and provided personal observations on comfort and performance.

The monitoring is described in further detail in Chapter 2.

5. PRELIMINARY RESULTS AND DISCUSSION

A. Aesthetic

The energy saving systems were intergrated within the house so as to not intrude on the occupants' comfort and living patterns. This integration demonstrated the co-habitability of energy conservation and modern lifestyle. Visitors would not have immediately noticed the energy features if they had not been pointed out.

The temperature in the house was normally within the usual comfort range of 18 C to 24 C, throughout the summer and winter. In the winter, cooler temperatures down to 16 C were measured on mornings after an extremely cold night. Warmer temperatures occurred when the wood stove was overstoked. In the summer, the window overhang and the forest provided good shading from the sun. The heat storage bank provided any extra cooling required.

The house responded very slowly to outdoor temperature fluctuations, due to its long time constant. A time constant, or thermal lag factor, is a measure of the amount of thermal mass in the house compared to the insulation level, and indicates how quickly the house responds to outside air temperature changes. ER-1 has a time constant in the order of 60 hours (compared to 10 hours in typical houses of standard construction).

The humidity levels achieved were very satisfactory. In the winter, the humidity reached a low of 30% with the outdoor temperature at -40 C, but usually stayed around 40% to 50%. The high humidity made skin feel moist, the use of moisturizing lotions was reduced, and plants did not have to be watered as often. The ER-1 occupants report that the severity of colds and sore throats was greatly lessened. These observations are corroborated by reports on other well-sealed houses (Green, 1979, 1982).

In the daytime, particularly in the winter, the light levels were high and well distributed. This gave a very pleasant feeling to the house in the long and usually dull winter months.

B. Energy

During the heating season of 1981/82, only the wood stove was used to provide supplemental space heating. This was specifically to demonstrate the capability of wood stoves to

supply space heat. Approximately 20 GJ of wood energy (a volume of 1.8 cords) was used for space heating, equivalent to $75 worth of natural gas burned in a standard furnace at 1981 prices.

Approximately one-third of the water heating in 1982 was supplied by the grey-water heat exchanger and the passive solar water heater. The rest was supplied by the electric water heater at a cost of $150 for the year.

C. Demonstration

A guest book was kept to record the visitors to the house. Date, name, occupation, and area of residence were recorded to indicate the cross-section of people who had visited. Although no general public tour or open house has been arranged, 185 people visited during the first year. Visitors were usually friends or acquaintances, or people who had asked to see the house. A few government departments and companies arranged tours for specific groups or staff. Interest in the research was expressed by several research groups and a utility company.

Three film crews visited to take pictures of the energy features, and conduct interviews on lifestyle for general documentary films. One reporter interviewed for a magazine article.

Reaction to the house and to the energy systems varied. Some people were indifferent to the energy features. Others were surprised that leaving out a standard furnace would be considered in such a cold climate. In general, much keen interest and enthusiasm was expressed.

CHAPTER 2. OVERVIEW OF THE MONITORING PROGRAM

1. SUMMARY

A program of monitoring was set up in ER-1 to assess the performance of the research projects. Electronic and manual methods measured air, water and soil temperatures, solar energy gains, water, electricity and wood consumption, and relative humidity. Notes were made on observed performance details and on the aesthetic impact of the projects.

2. BACKGROUND

The monitoring of ER-1 was set up for the following purposes:

- to determine the performance of the research projects.
- to assist in fulfilling the requirements of the research grants.
- to provide high quality performance feedback to the designers, and to the conservation, solar energy and building industries.

Many details on residential energy performance research have been reported by the Solar Energy Research Institute (1979, 1980). The revolution in micro-computers has brought sophisticated electronic monitoring capability within the reach of individuals and small organizations (Moore, 1982). Previously, capital equipment budgets of several tens of thousands of dollars were required for research, effectively eliminating small organizations from carrying out a detailed monitoring program.

The program of monitoring was designed, and the systems installed and programmed by D. Gordon Howell. Valuable design assistance was provided by G. M. Rekken, and installation assistance by C. G. Rekken and D. W. Patterson.

3. SYSTEM DESIGN

The objective in designing the monitoring program was to provide performance results with reasonable accuracy and low cost. Three methods of monitoring were employed:

- automatic measurements by an electronic system,
- manual measurements and readings, and
- observations.

A. Electronic Monitoring System

1) Equipment

The electronic monitoring system consisted of a standard Apple II Plus micro-computer and a Hewlett-Packard 3497A Data Acquisition Unit, shown in Figure 2.1. The Apple was connected to several peripherals:

- two 140 kilobyte Apple disk drives,
- a Centronics 739 dot matrix printer,
- an Apple IEEE 488 interface for communication with the Data Acquisition Unit,
- a DC Hayes Micromodem for telephone communication,
- a NEC character display with 80 column capability, and
- an Interactive Structures digital interface for sending and receiving control and status information.

Figure 2.2 shows the connections of the Apple, the Data Acquisition Unit and the peripherals. The Data Acquisition Unit had two multiplexed signal conditioning interfaces capable of accepting 40 voltage inputs. It also included a programmable current source, autoranging voltmeter with microvolt resolution, and a 120 dB common mode rejection ratio (Hewlett-Packard, 1980).

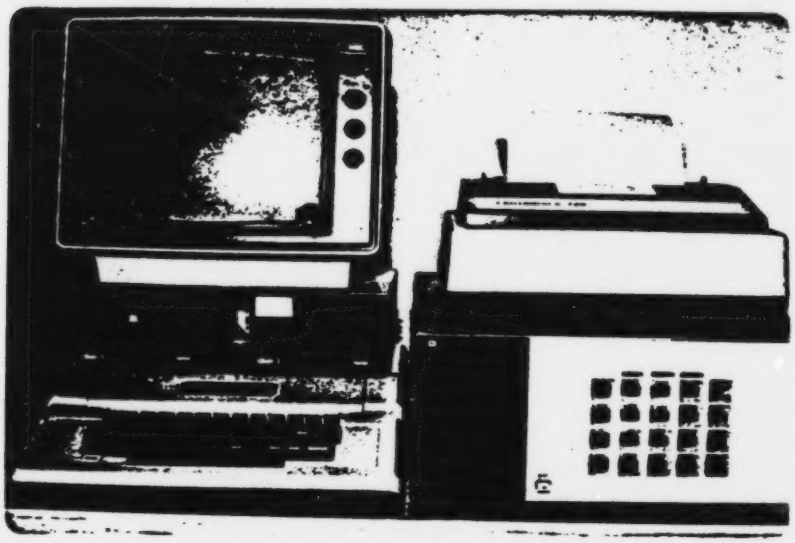

Figure 2.1 Electronic monitoring equipment

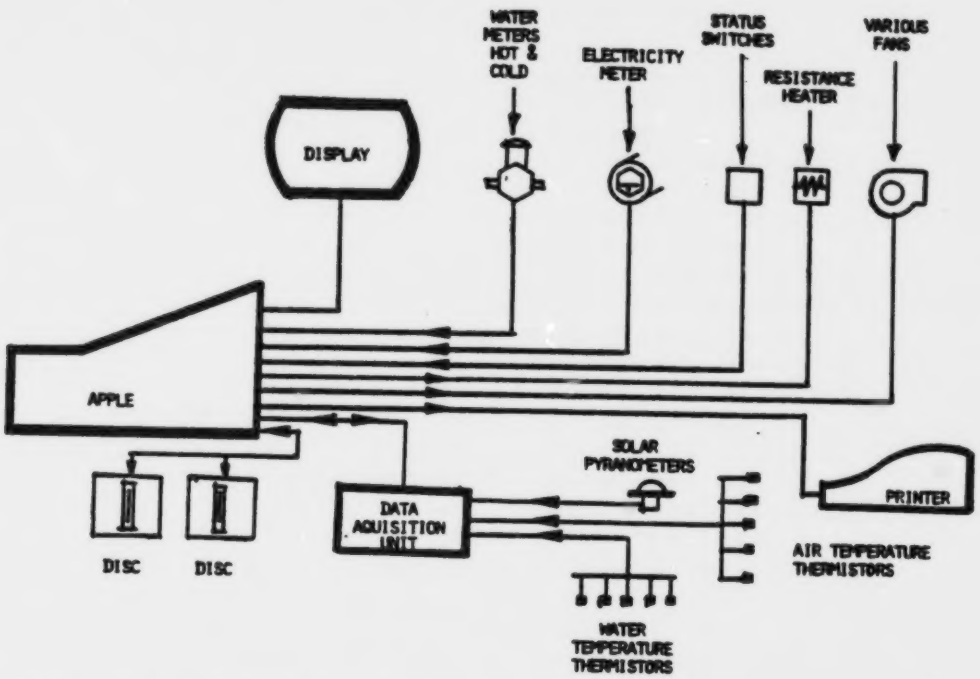

Figure 2.2 Schematic of the Electronic Monitoring System

The electronic system measured several performance factors on each of the research projects. These are listed in Table 2.1.

2) Sensors

a) Thermistors (temperature measurement)

Thermistors made by the Yellow Springs Instrument Company of Ohio, USA, were used to sense air and water temperatures. These are electronic devices which change resistance as a function of temperature. Those specified for monitoring ER-1 had a resistance of 5000 ohms at 25 C.

The Data Acquisition Unit applied an excitation current of 10 microamperes to a thermistor at the time of measurement, and transmitted the resulting voltage reading to the Apple. The computer program then calculated the resistance and applied the Steinhart-Hart linearizing equation (Flora, 1980) to determine the corresponding temperature.

Table 2.1 Performance factors measured by the electronic monitoring system

Air Temperature	Sensor accuracy (C)
1. Outside air	0.1
2. Dining room	0.1
3. Upper hallway	0.1
4. Clerestory windows	0.2
5. Guest bedroom	0.2
6. Main bathroom	0.2
7. Upper greenhouse	0.2
8. Lower greenhouse	0.2
9. Fresh-air inlet to heat exchanger	0.1
10. Fresh-air outlet from heat exchanger	0.1
11. Stale-air inlet to heat exchanger	0.1
12. Stale-air outlet from heat exchanger	0.1
13. Upper heat bank inlet	0.1
14. Lower heat bank inlet	0.1
15. Six positions in heat bank	0.2
21. Living room vent	0.2
22. Wood stove	0.2
23. Garage	0.2

Water Temperature	Sensor accuracy (C)
1. Potable water inlet to heat exchanger	0.1
2. Potable water outlet from exchanger	0.1
3. Solar water heater inlet	0.1
4. Solar water heater oulet	0.1
5. Hot water from electric water heater	0.2
6. Grey-water inlet to heat exchanger	0.1
7. Grey-water outlet from heat exchanger	0.1

Solar Radiation, sensor accuracy: 4%

1. Horizontally incident
2. Vertically incident
3. Transmitted by glass
4. Transmitted by forest
5. Available to the solar water heater

Water Flow, resolution: 1 litre

1. Total water consumption
2. Domestic hot water consumption

Table 2.1 (continued)

Electricity, resolution: 25.92 kJ

1. Total electricity consumption

Status

1. Operation of electric space heater by thermostat
2. Operation of fresh-air heat exchanger by humidistat
3. Operation of clothes dryer

Control

1. Electric space heater
2. Fresh-air heat exchanger
3. Recirculating air fan
4. Direction of air flow through heat vent

Thermistors having two different accuracies were used: 0.1 C, and 0.2 C. The 0.1 C thermistors were used at locations where sensitive, small-scale differential temperatures were being measured. The 0.2 C thermistors were used at locations of less sensitivity.

Since the thermistors were affected by moisture, they were coated in paraffin wax before being installed. The thermistors that measured water temperatures were also placed inside a thermowell.

b) Pyranometers (solar radiation measurement)

Moll-Gorczynski pyranometers made by Kipp en Zonen of Delft, The Netherlands, were used to measure solar energy parameters (Fritschen and Gay, 1979; Latimer, 1971). These sensors produce a small voltage as a function of solar radiation intensity, typically 10 mV at 1000 W/m2.

The pyranometer voltage was read by the Data Acquisition Unit and transmitted to the Apple. The computer program applied individual calibration factors and temperature compensation coefficients to determine the corresponding intensity.

c) Water flow meters

Neptune flow meters were used to measure water consumption and flow rate. The meters were similar to standard house water meters, but were fitted with a

switch which provided a pluse to the Apple's digital interface for every litre of water passing through.

d) Electricity meter

The electricity meter used for billing was manufactured by Sangamo, and fitted with an electronic pulse output circuit. The meter sent a pulse to the Apple's digital interface for each rotation of the meter's disk, corresponding to 25.92 kJ of electricity.

e) Switches (sensing system status)

In addition to controlling their respective functions, the thermostat and humidistat provided a status output to the digital interface of the Apple.

f) Relays (system control)

Solid state relays were connected to the digital interface to give the Apple control over four devices: the electric space heater, fresh-air heat exchanger, air recirculating fan, and heat bank air direction dampers. This control capability was installed to allow innovative and complex control algorithms to be programmed into the Apple.

3) Data Gathering

The electronic monitoring system gathered, manipulated and recorded data using a monitoring program on the Apple. Conversion of sensor voltages, resistances and pulse readings into meaningful data, and integration, averaging and other manipulation of the data was performed by the program.

The system was very flexible. Any type of equation or display format could be programmed into the Apple to show whatever performance factor was required.

Every 30 seconds the computer executed a scanning routine. It read inside and outside air temperatures, and determined their maxima and minima. Status switches were interrogated and control decisions made. Temperatures of the mechanical systems that were in operation during the scan were read. Thirty second summaries of pulses received from the electricity meter and the water meters were made.

Solar radiation readings were taken every 10 seconds during the daylight hours. Maxima and sums were calculated from the readings.

A 5 minute average electricity load was calculated from the electricity meter pulses to form daily load profiles.

The computer program displayed system data onto a video display terminal. Each system had its own display which could be selected from the keyboard, showing temperatures, flow rates, ratios, efficiencies and other values appropriate to the system.

B. Manual Measurements and Readings

Manual measurements were taken at several locations where changes in readings occurred slowly. Table 2.2 lists these sensors. Measurement data was recorded on paper.

Thermistors were implanted in the soil to determine the heat loss from below grade portions of the house envelope. Locations of these sensors included the footings at several depths outside a below grade wall, and below the concrete foundation slab. The soil temperatures were read weekly using a Fluke 8024B Digital Multi-Meter.

Two additional electricity meters were installed on ER-1 to monitor the electricity used by the electric water heater, and the electric space heater. The three electricity meters and the two water meters were read daily.

The wood consumption was measured using a heavy duty kitchen scale. The weight and a general type classification (eg. poplar, spruce, waste paper, newspaper) were recorded.

C. Observations

Observations on the operation of ER-1 were incorporated into the program of monitoring. The occupants noted several factors, including comfort, humidity, temperature, temperature fluctuation and uniformity, convenience and appearance, odour, and air quality.

The observations assisted in assessing the aesthetic factors of the various systems, and in interpreting the performance results.

Table 2.2 Performance factors measured or read manually

Soil Temperatures, 0.2 C accuracy

Footings:
1. south side, 600 mm deep
2. north side, 2600 mm deep

North wall depth profile:
3. 2000 mm
4. 1000 mm
5. 500 mm
6. 250 mm
7. 100 mm

Under foundation slab:
8. living room
9. workshop at 200 mm
10. workshop at 800 mm
11. laundry room

Electricity Consumption

1. Total
2. Space heater
3. Water heater

Water Volume

1. Total
2. Hot water

Wood Consumption

1. Space heating

CHAPTER 3. CONSTRUCTION AND BENEFITS OF THE SUPER-INSULATION SYSTEM

1. SUMMARY

The costs and benefits of the super-insulation system on ER-1 were assessed. Factors considered in the assessment included construction cost (both reductions and extras), the health and comfort benefits, and the savings in energy. The assessment shows that the net extra costs are minimal, and the benefits significant.

2. BACKGROUND

With the rise in energy prices came several new and innovative residential wall designs. They featured thicknesses capable of containing very high insulation levels. Some designs also included good protection of the air/vapour barrier.

The widely used term, "super-insulation", was then defined to describe wall systems with insulation levels exceeding Rsi 4.4. This is the approximate value above which the walls must be of some construction other than 2x6, or 2x4 with insulated sheathing (Dumont, personal communication).

Included in the new super-insulation designs are the double stud wall, the Larsen truss, staggered stud, 2x6 with exterior insulated sheathing, and 2x6 with interior strapping (Alberta Agriculture, 1982).

3. SYSTEM DESIGN

The objective in designing and constructing ER-1 was to reduce heating costs in a practical manner through moderately high insulation and air-tightness levels. The major thermal loss factors of the house are:

1. Wall thermal resistance..... Rsi 5.5
2. Ceiling thermal resistance..... Rsi 7.9
3. Air infiltration rate at 50 Pa..... 1.09 AC/h (see also Chapter 10)
4. Number of window glazing layers..... 3
5. Total heat loss rate at -37 C..... 6500 W

The components used in the envelope construction are listed in Appendix B. The above grade walls were made of 2x6 studs with 2x3 interior ribbons and exterior insulated sheathing. The roof consists of a non-ventilated cavity of 2x10 rafters with exterior 2x4 purlins, filled completely with insulation.

4. ASSESSMENT TECHNIQUES

To assess the benefits of the super-insulation systems, several parameters were considered:

A. The Construction Experience

This parameter assesses the advantages and disadvantages experienced with the method of constructing ER-1.

B. The Extra Construction Costs

This parameter includes the extra incurred costs of the materials and labour in the house envelope and the heating and ventilation systems.

C. The Construction Cost Savings

Several areas of savings arose from simplified construction and installation methods. Air circulation and heating system capacity requirements were significantly reduced because of the low energy construction. This parameter includes the estimated costs of the eliminated components and labour.

D. The Predicted and Measured Energy Performance

The energy performance of the house was estimated in the design stage through the use of a simple computer analysis program. This estimation was evaluated over the winter of 1981/82 by recording the amount of energy used in normal house activities, and the required supplemental space heating energy.

E. The House Operation

This paramter describes the operating and comfort factors of the house over the winter of 1981/82 and the following summer.

5. PRELIMINARY RESULTS AND DISCUSSION

A. The Construction Experience

1) Below Grade Framing

The main floor north wall and one half of the main floor east wall is below grade and was constructed of 2x8 preserved wood studs. Particular care had to be taken with the design and construction of the below grade section to ensure that a reasonable lifetime was guaranteed. Considerable supervision and additional input during construction was required to avoid problems.

Difficulty was experienced in acquainting the carpentry trades with the details required to properly secure the below grade walls against the potentially large earth pressures. More care and attention to detail was required in constructing these walls. Backfilling also required particular caution to avoid stressing the walls beyond their design loads.

Below grade exterior plywood sheathing must be protected from soil moisture. On ER-1, 250 micrometre polyethylene sheeting was applied on the outside of the plywood, and then backfilled. The dirt completely covered the poly and protected it from exposure and degradation by ultra-violet radiation.

2) Above Grade Framing

The house was framed in a standard manner using 2x6 studs at 600 mm centres. The trades had no objection to the use of this material and did not experience any difficulty or significant extra labour with this stud spacing.

The horizontal 2x3 ribbon framing was applied at 600 mm centres to the interior of the stud wall, after the insulation and air/vapour barrier (a/vb) had been installed. Figure 3.1 shows the construction of the above grade wall, with the a/vb in between the ribbons and studs. No difficulty was experienced with this method, but the ribbons did require a separate labour operation.

RECOMMENDATION

It is recommended that the ribbons be applied at 400 mm centres rather than 600 mm. This would increase the support of the drywall.

The freedom of the electrical trade to run wires horizontally in the exterior walls without drilling was a distinct advantage, and they made a point of saying so. In addition, the ribbons provided wiring space on the inside of the air/vapour barrier, eliminating punctures by the wires and the need for protective polyethylene covers on the electrical boxes. This detail saved time and labour.

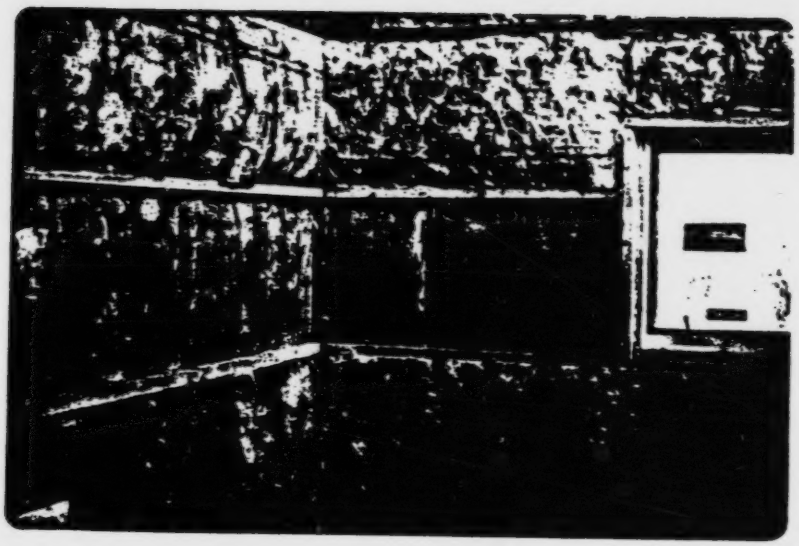

Figure 3.1 Above grade wall detail

3) Roof Framing

The roof was framed with standard 2x10 cathedral ceiling rafters, with 2x4 purlins on the exterior to increase the insulation depth to 325 mm. No difficulty was experienced with this framing method. The extra labour was not significant. It was, however, necessary to have an insulator available before the roof sheathing was applied, to fit the Rsi 2.1 batts between the purlins.

4) Air/Vapour Barrier

A polyethylene air/vapour barrier, 135 micrometres thick, was used throughout the house. This thickness is strongly advised as it will most practically withstand the abuse of construction.

The a/vb in the above grade walls was located at a point where one quarter of the total insulation value was on the warm side. As much as one third of the insulation can be on the warm side without concern for moisture condensation. On the ceiling, the a/vb was applied next to the drywall.

The caulking was done by the contractor. Some planning was required when trying to seal the edges of two sheets

of air/vapour barrier together, and where it had been poorly installed by the framing crew. A sub-trade, experienced in air/vapour barrier installation, would be valuable.

RECOMMENDATION

It is recommended that windows have an a/vb strip wrapped around and caulked to the frame before shimming into position (Orr, 1979; Hughes, 1982). Enough of the a/vb should be gathered at the corners of the window to allow it to lie flat once installed. This allows the a/vb from the wall to be easily and securely caulked to the windows.

The poly strips on the windows were inadvertently missed on ER-1. To effect a similar seal, the wall a/vb was caulked and stapled directly to the window frame before the extensions were installed. An a/vb patch was required as well to seal each window corner.

Two cases of acoustic sealant caulking, each containing twelve 810 ml tubes, were used to seal the house. It is extremely important to use an acoustic sealant as it does not harden, retaining over time its ability to adhere to the a/vb.

The sealant was purchased from two suppliers: one case was ChemTron Metaseal from Alberta Drywall Products, and one case was PRC from Steel Brothers. The PRC was a much stiffer compound. The Metaseal was stickier and appeared to adhere better, but it continued to flow out of the tube after all the pressure had been released. This required it to be set down on a piece of plastic after each bead of caulking to prevent sticky sealant from falling on the floor and being tracked throughout the construction site.

5) Window Installation

The framing of windows in super-insulated walls is similar to standard construction practice. However, extensions to window jambs are usually required because of the extra wall thickness.

There is some question in the industry today regarding placement of the windows toward the inside of the wall depth or the outside. The outside placement allows for a nice large window ledge on the inside, but reduces the

window temperature. The inside placement keeps the window warm and helps to eliminate any condensation in the winter by protecting it from outside winds, and allowing house air to sweep past.

RECOMMENDATION

It is recommended that windows be placed toward the inside of the wall, especially in high humidity situations and when double glazing is used.

The type of material used for the extensions should be considered carefully. Drywall material may be susceptible to degradation if a severe amount of window condensation forms, melts and collects on the extension.

ER-1 was fitted with triple-glazed windows and no condensation problems were expected (see also Chapter 6). Extensions were made of GIS plywood instead of the more commonly used, and more expensive finished fir.

Window frames, mouldings and extensions were painted to blend in with the walls and decor.

6) Exterior Finish

The frame walls were sheathed on the exterior with GLASCLAD high density glass fibre rigid insulation. Difficulty was experienced, however, in the application of stucco. The trades were frustrated with the absence of plywood for positive attachment and overall rigidity. It would appear that stucco is a poor covering for insulated sheathing.

B. The Extra Construction Costs

The extra cost of the insulation, air tightness and the systems for ventilation and supplemental heating was approximately $7200. This includes:

- framing materials..... $ 700
- framing labour..... $ 600
- insulation materials..... $1200
- insulating labour..... $ 150
- air/vapour barrier & acoustic sealant..... $ 200
- caulking of the air/vapour barrier..... $ 500
- extra cost of triple-glazed windows..... $1000
- installation and caulking of the windows..... $ 400
- materials and labour for window extensions..... $ 500

- fresh-air heat exchanger, installed..... $1300
- air recirculating fan, installed..... $ 350
- electric in-duct 6 kW space heater, installed.... $ 100
- electric water heater, installed..... $ 200

Extra construction cost TOTAL $7200

C. The Construction Cost Savings

The total savings due to simplified construction and eliminated mechanical systems were estimated to be $3800. This includes:

- simplified electrical wiring because of horizontal ribbons on exterior walls..... $ 50
- omitting the attic ventilation components due to the well sealed air-vapour barrier..... $ 250
- omitting the natural gas line (acreage price).... $1200 *
- omitting the natural gas furnace, installation and connection..... $1000
- omitting the furnace flue, its framing and installation..... $ 600
- omitting the natural gas water heater and installation..... $ 200
- reducing the size and number of heating ducts from 17 to 7, including installation..... $ 500

Construction cost savings TOTAL $3800

NOTE: See Chapter 11 for a discussion on economics.

* The cost of installing a natural gas line depends on the location of the residence, whether it is on a city lot, acreage, or farm. Natural gas line installation in 1983 in Edmonton costs $50, plus $15 per metre from the lot line to the house. The full cost of installing natural gas service to a subdivision is included in the price of natural gas.

* The 1983 price for natural gas installation on acreages serviced by Northwestern Utilities is $1520 per lot. Natural gas service to farms costs $1520 to the customer plus $8950/km in subsidies from the Alberta Government.

D. The Predicted and Measured Energy Performance

The average yearly heat loss was estimated by the computer analysis program to be 81 GJ (Appendix C). Approximately 75% of this or 61 GJ would have been supplied by solar energy and heat from electrical appliances, and the rest required as supplemental space heating energy.

The heating load for ER-1 at -37 C was calculated to be 6.5 kW, equivalent to the power consumption of four toasters. It was projected to use 20 GJ of energy for supplemental space heating. In comparison, if built by standard construction methods, it would have required a 17 kW furnace (output rating) and used 129 GJ of energy for space heating (Appendix D).

Atmospheric Environment Service meteorological summaries show that in the heating period from October 1981 to April 1982, the number of heating degree-days was 5210 or 5% colder than the long term normal. There were 978 hours of bright sunshine, 2% less than the normal. In this period, supplemental space heating energy, which was supplied solely by wood, amounted to approximately 21 GJ.

Althought the actual supplemental energy consumption appears to show good agreement with the predicted energy consumption, several independent assumptions were used to arrive at both figures. Continued monitoring of the house will provide further evaluation of its energy consumption patterns throughout the year, and assist in refining the predictive capabilities of the analysis program.

In Table 3.1, a breakdown of the supplemental energy and costs for space and water heating for ER-1 as constructed can be compared with the energy requirements predicted by the computer program for a house of similar dimensions but of standard construction (Appendix D).

E. The House Operation

The comfort and operation of the house was detailed extensively in the reports issued monthly throughout the testing period of 1981 July to 1982 June (Howell, 1982). A summary will be included here.

The house temperature was generally warm in the winter, with a few periods of overheating due to inexperience in stoking the wood stove (burning too much at once). The temperature was allowed to float during the days and nights when the occupants were at work or asleep. During the periods of coldest outside temperatures, the house temperature never dipped below 16 C at night. With the wood stove in operation, the house easily remained at 21 C.

Because of the well sealed air/vapour barrier, the house envelope was able to control air moisture loss, and a humidifier was not needed. The house air never felt dry. Relative humidity levels reached a low of 30% when the outdoor air temperature was at the extreme minimum, but generally stayed at 40% to 50% (see also Chapter 10).

Table 3.1
Supplemental Heating Energy and Costs for 1981/82
- ER-1 Compared to Standard Construction

	SPACE ER-1 wood*	WATER ER-1 electricity	SPACE & WATER Standard construction with natural gas**
Service charge	fir: $6/m3 poplar: $1	no extra charge for water heating	$6.50/month
Price in 1981/82	fir: $4/m3 poplar: $0	$12.13/GJ	$2.45/GJ avg 9.14 ¢/m3
Material consumption	fir: 1 m3 poplar: 5.7 m3	12.6 GJ	6000 m3
Heating efficiency	60%	100%	65%
Net energy consumption	21 GJ	12.6 GJ	144 GJ
Total cost	$11	$150	$625

NOTES: * Heat energy from wood is very difficult to estimate. These are approximate values only of actual wood heating and consumption costs. A total of 6.7 m3 (1.8 cords) of wood was used in the 1981/82 winter. See Chapter 9 for more details.

** Natural gas was not installed and not used. This represents only the natural gas costs for a house of standard construction.

Indoor summertime temperatures were always very pleasant. Temperatures ranged between 18 C and 24 C. Overheating was not a problem, even when the windows were closed for extended periods. A number of factors contributed to prevent overheating:

- The overhang on the clerestory windows blocked out the direct summer sun completely.
- The poplar woods to the south shaded the lower windows effectively from May until October.
- The high thermal resistance of the house envelope contributed significantly to reduced heat gain from the roof, which was not shaded from the direct sun.
- The openable clerestory windows provided an excellent cross-ventilation capability.
- The short term heat storage bank provided for any excess cooling requirements (see also Chapter 5).

CHAPTER 4. SOLAR ENERGY SYSTEM

1. SUMMARY

The solar energy gain was monitored to evaulate its impact on the house performance. Sensors determined incoming solar energy on a horizontal surface, and the effects of 90 degree surface tilt, window glazing, and forest shading. The design analysis estimated that approximately 60% of the annual supplemental space heating requirements of ER-1 would be supplied by solar energy.

2. BACKGROUND

Solar energy is electromagnetic radiation emanating from the sun with wavelengths measuring between 0.3 and 3 micrometres. In the past, data on the availability of solar energy has been generally scarce. Today, because of the growing utilization of solar energy, these data requirements are being met.

In Alberta, the Atmospheric Environment Service of Environment Canada has three solar monitoring stations, at Beaverlodge, Stony Plain and Suffield. The Alberta Research Council is operating seven stations, at Fort McMurray, Ellerslie, Edson, Coronation, Rocky Mountain House, Lethbridge, and Pincher Creek. A number of other stations are collecting solar data for specific projects.

Across Canada, research is continuing on mathematical solar energy prediction models, (Hay, 1977; McArthur, 1980; Davies, 1981; Atmospheric Environment Service, 1980). Barakat (1980) has published solar energy data for many places using computerized estimation techniques. Alberta locations include Edmonton and Suffield.

Some misconceptions exist regarding solar availability and its value in northern climates. These misconceptions include ideas that are not complete and can be misleading, such as "solar energy gains decrease dramatically in the winter", and "overhangs alone are sufficient to optimize control of solar gains".

3. SYSTEM DESIGN

The objective in designing and constructing ER-1 was to achieve high but controllable solar gain levels. The large amount of south-facing window area provides for the solar gains, and can be thought of as the solar collectors. Table 4.1 details the window configuration.

Triple glazing was used for all windows except the solar water heater, to control condensation and heat loss in the winter, and overheating and glare in the summer. Summer shading is provided by overhangs and a forest consisting of mature poplar trees.

Clerestory windows allow daylighting and solar heating to the upper floor rooms on the north side.

The window for the solar water heater was double-glazed and slanted at 56 degrees, an optimal angle for year-round water heating (Figure 4.1). All other windows were installed vertically for practical reasons:

- to eliminate snow build-up,
- maximize winter heating,
- eliminate summer overheating, and
- ease of construction.

Table 4.1
Window configuration

	LOCATION	ORIENTATION	NUMBER OF GLAZINGS	AREA m2	SHADING MECHANISM	TILT degrees
1.	Main floor	south	3	11.1	forest	90
2.	Clerestory	south	3	4.1	overhang	90
3.	Water heater	south	2	1.8	none	56
4.	Bedroom & Greenhouse	east	3	2.1	forest	90
5.	Bedroom	west	3	0.8	none	90
6.	Kitchen	west	3	0.4	overhang	90
7.	Bedroom	north	3	0.3	none	90

Total glazing area: (m2) south 17.0, east 2.1, west 1.2, north 0.3

4. ASSESSMENT TECHNIQUES

The measurement of solar energy was designed to provide more understanding of the performance of windows and landscaping in admitting and controlling solar gains relative to house energy requirements. Devices called pyranometers were set up to measure several solar parameters:

1. Incident on an unshaded horizontal surface

Collection of this data is standard at most solar monitoring locations. This pyranometer can be compared with the AES Stony Plain Upper Air Station (SPUAS) located 5 kilometres away.

2. Incident on a vertical surface

This pyranometer measured the effect of tilting a collecting surface to 90 degrees. When tilted, a collector "sees" less

of the sky and more of the ground. Reflected energy from snow then becomes important to the surface and can add significantly to the incoming energy in the winter.

In addition, when a collector is tilted at near vertical angles, it sees the energy density of the direct solar beam as higher in the winter and lower in the summer. This is the opposite to that for horizontal angles, and has a special significance for northern latitudes.

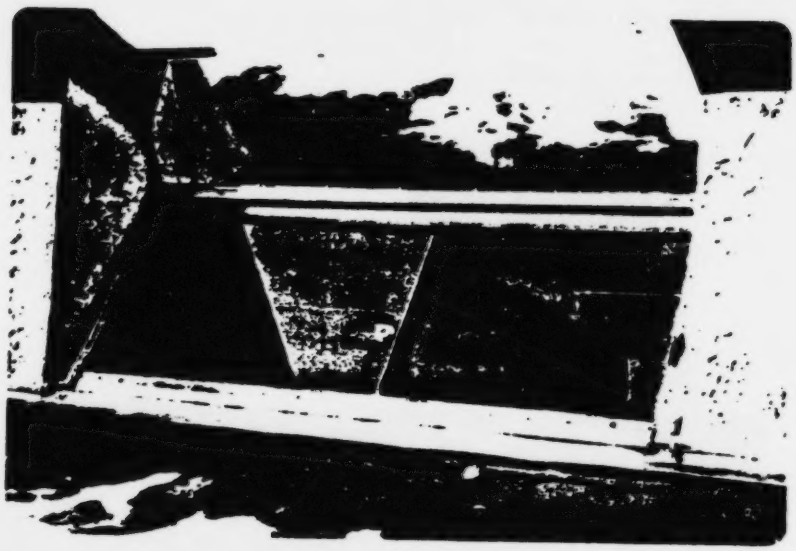

Figure 4.1 Passive solar water heater showing tilted window and reflector

3. Transmission through a vertical triple-glazed window

This pyranometer was placed behind a triple-glazed window and measured the shading factor of the glass. This factor can be used to calculate the solar energy directly available for space heating.

The shading effect of glass depends on the incident angle of the solar beam. In the case of vertically tilted glass, a higher portion of solar energy is transmitted in the winter since the angle of the sun is nearly perpendicular to the glass. By contrast, the solar altitude angle in the summer is very high, and rather than being transmitted, much more of the radiated energy is reflected or absorbed.

4. Transmission through the forest

This pyranometer was installed in the forest at ground level and measured the shading effect of the forest on a vertical surface.

Pyranometers #1, #2, and #3 were installed in a specially designed, ventilated test enclosure, which was set on the roof of ER-1 to maximize solar exposure (Figure 4.2). Some shading by trees did occur in the early morning and late evening.

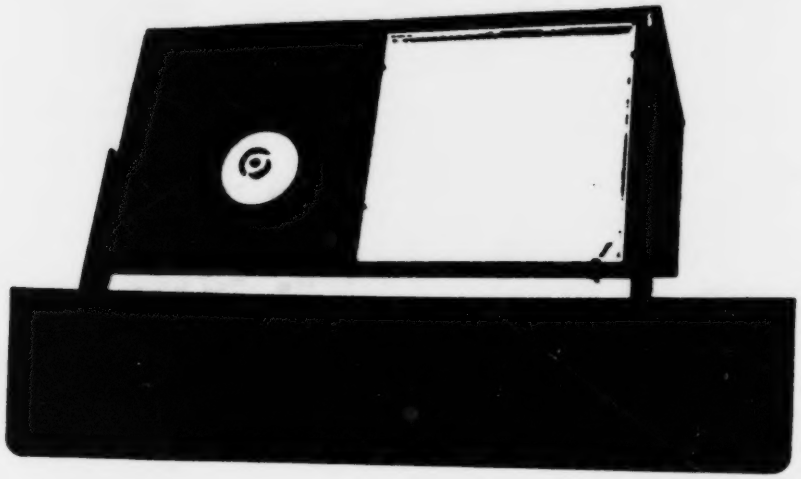

Figure 4.2 Solar sensor test box showing pyranometers #2 and #3

A fan system was installed to blow air around the pyranometers at all times. This constant movement of air kept the instruments clear of snow, frost, dust, dew and rain and thus ensured representative results. The pyranometers were calibrated at the Solar Calibration Laboratory at Atmospheric Environment Service in Downsview, Ontario.

Measurements on the pyranometers were taken every ten seconds by the monitoring system. Temperature compensation was applied, and the values were integrated. Daily records were kept.

5. PRELIMINARY RESULTS AND DISCUSSION

A. Horizontal Solar Energy

The solar energy data measured on a horizontal surface is shown in Table 4.2. Data from ER-1 for 1982 can be compared with data collected by the Atmospheric Environment Service's Stony Plain Upper Air Station, with data calculated by Hay (1977) for an average year at the SPUAS, and with SPUAS long term data.

The difference between data collected at ER-1 and SPUAS in the summer of 1982 was due to the forest shading in the early morning and late evening.

Table 4.2
Solar energy on a horizontal surface (MJ/m2.day)

	ER-1 1982	SPUAS 1982	Hay average	SPUAS average
January	*	3.4	3.7	3.6
February	*	7.4	7.1	7.1
March	*	12.6	12.5	12.5
April	*	19.8	17.5	17.5
May	17.9	21.6	20.6	20.2
June	19.4	22.0	22.0	21.6
July	17.0	20.0	22.6	21.7
August	15.7	17.6	18.3	18.2
September	10.8	12.9	12.7	12.3
October	7.7	8.4	7.8	7.6
November	3.8	3.9	4.0	4.0
December	2.2	2.2	2.7	2.6

* No data was available at the time of writing.

B. Effect of Vertical Tilt

The effect of tilting a collector can be seen by comparing solar data with a vertical surface and solar data from a horizontal surface.

Table 4.3 lists the solar energy on a vertical surface measured at ER-1, as calculated for an average year by Hay (1977), and the vertical to horizontal ratios for both data sets. As expected, the ratio is seen to increase in the winter due to the lower sun angles and decrease in the summer. The ratios also vary widely on a daily basis, depending on the amount of cloud cover.

Differences between long term average ratios and the yearly ratios can be attributed to several factors, including climate variations. This underscores the importance of long term solar data and its effect on design and performance estimation.

C. Effect of Triple Glazing

The shading effect of triple glazing was determined by comparing pyranometer #3 with #2. Both instruments had the same 150 degree view, with #3 also being behind the test window (Figure 4.2). Table 4.4 compares the monthly averaged transmission factor of the triple-glazed test window on ER-1 with that calculated by Barakat (1980) at the National Research Council.

One factor contributing to the difference in the data values is that the ER-1 data does not include the solar energy absorbed by the glass and reradiated to the interior as heat. The data produced by NRC does account for this (Barakat, personal communication).

D. Effect of the Forest

Table 4.4 also shows the monthly averaged transmission factor of the deciduous forest surrounding ER-1. As with the other factors, the shading does not remain the same from day to day. The value varies by greater than 0.2, depending on the cloudiness of the sky.

The daily data clearly showed the onset of spring and winter with the arrival and disappearance of the leaves. Within a two week period, the transmission factor fell from 0.80 to 0.50 in the spring, and rose from 0.40 to 0.60 in the fall.

E. Contribution of Solar Energy to Heating Requirements

The value of solar energy's contribution to heating equals the savings in supplementary energy costs. (The total value of solar heating must, of course, include its contribution to daylighting and persons values. These other aspects are discussed further in Chapter 11.)

Solar energy provided a significant amount of the space heating energy of ER-1. Appendix C shows the yearly savings in electric heating due to solar energy equals $412 at 1981 prices. This value is 42% of the total space heat consumed by ER-1 and 62% of the required supplemental heat.

Table 4.3
Solar energy on a vertical surface (MJ/m2.day)

	Vertical surface		Vertical tilt ratio	
	ER-1 1982	Hay average	ER-1 1982	Hay average
January	*	8.7	1.82	2.34
February	*	12.1	1.37	1.71
March	*	15.5	0.95	1.24
April	*	14.9	0.72	0.85
May	9.3	13.2	0.52	0.64
June	9.0	12.2	0.46	0.56
July	8.8	13.1	0.52	0.58
August	9.9	13.2	0.63	0.72
September	10.8	12.7	0.99	1.01
October	12.5	11.9	1.62	1.53
November	6.9	8.7	1.83	2.17
December	4.0	6.7	1.76	2.48

* No data was available at the time of writing.

Table 4.4
Transmission factors for
the triple-glazed windows, and the forest

	Triple-glazing		Forest
	ER-1	Barakat	ER-1
January	0.56	0.70	0.63
February	0.55	0.69	0.64
March	0.53	0.67	0.67
April	0.51	0.65	0.74
May	0.58	0.62	0.75
June	0.52	0.61	0.52
July	0.51	0.61	0.48
August	0.55	0.64	0.45
September	0.58	0.67	0.39
October	0.58	0.69	0.63
November	0.56	0.70	0.64
December	0.55	0.70	0.66

For comparison with a house of similar dimensions, built with standard construction methods (Appendix D), the yearly savings in natural gas would be $150 (1981 prices). These savings are 20% of the total space heat consumed, and 24% of the required supplement.

This example shows the higher solar energy potential that can then be realized in low energy houses. A much greater emphasis can be placed on solar both in terms of its dollar value and percentage of contribution.

F. Solar Heating in Northern Latitudes

The general public appears to feel that the major concern in heating with solar in Alberta's latitudes is a lack of solar energy in the wintertime. More correctly, the effect of extreme temperatures on heating requires a large emphasis on energy conservation.

Although the solar energy available on horizontal surfaces show an eight-fold decrease from June to December (Table 4.5), vertical surfaces, not horizontal, are important in residential solar heating applications.

Shown in Table 4.5 are values of incoming solar energy for horizontal and vertical surfaces (Hay, 1977), and energy availability through south-facing triple-glazed windows, using the monthly glazing factors from Table 4.4. The large seasonal variation is considerably reduced by the effects of vertical surfaces and glazing.

In comparing the total availability of solar energy between the heating and cooling seasons, the variations are even less pronounced. A horizontal surface as 2.3 times as much energy incident in the summer as in the winter, a vertical has 1.15, and the energy available for space heating only differs by 7%.

The effect of using triple-glazed, south-facing windows tilted vertically is summarized below. Over all, it can be seen that the combined effect serves to maximize the solar heating potential in the winter, and minimize the overheating potential in the summer.

Average solar transmission factor over the	heating season	cooling season
vertical tilt:	1.42	0.68
glass transmission:	0.67	0.63
combined effect:	0.95	0.43

Table 4.5
Solar energy available for space heating (MJ/m2.day)

	Incoming energy on a horizontal surface	Incoming energy on a vertical south surface	Energy for space heating with triple -glazed, vertical, south windows
January	3.7	8.7	6.1
February	7.1	12.1	8.3
March	12.5	15.5	10.4
April	17.5	14.9	9.7
May	20.6	13.2	8.2
June	22.0	12.2	7.4
July	22.6	13.1	8.0
August	18.3	13.2	8.4
September	12.7	12.7	8.5
October	7.8	11.9	8.2
November	4.0	8.7	6.1
December	2.7	6.7	4.7
Average energy gain, (MJ/m2.day)			
over the heating season (October - April)	7.9	11.2	7.6
over the cooling season (May - September)	19.3	12.9	8.1

CHAPTER 5. PRACTICAL ASPECTS OF THE HEAT STORAGE BANK

1. SUMMARY

The practical aspects of a short term heat storage bank were studied. The heat bank consisted of 447 trays of Glauber's salt phase change material located in an insulated compartment in the basement. Air from the ceiling of the house was directed through the stacked trays for heat removal or addition. The cooling mode of the heat bank worked well. Storage of heat appeared to be uncertain.

2. BACKGROUND

Short term heat storage systems are very common in solar houses in the southern USA. This is due in part to the high solar gain levels, the moderate climate and the frequent daytime need for air-conditioning. The result is a solar/conservation strategy that efficiently utilizes the heat storage capacity of heavy materials.

The heat storage systems in common use utilize the sensible heat storing capacities of water, masonry, concrete, or rocks in various configurations of thermal storage walls, rock beds, or roof ponds. In these systems, heat is stored or released when the temperature of the material rises or falls.

Less common systems use the latent heat capacity of phase change materials in drums or stacked trays. Phase change materials store most of their heat when they change their phase or melt from a solid to a liquid. The heat is released when they freeze. Typically, their heat storage capacity is many times greater than the sensible heat storage materials (Widmer, 1978).

In Alberta's climate, solar gain levels are not as high, and the climate is much more severe than in the southern USA. This suggests that the solar/conservation strategy should be directed more towards the saving of energy rather than the storage of energy from other sources.

There is still some potential, however, for the storing of energy in excess of the immediate heating requirements (storing heat from the day for use that night). If suitably designed, the house itself can present a certain amount of heat storage capacity in the foundation and interior walls. As well, heat storage units, that serve a multiple purpose can be used (as in a brick planter, or a masonry firplace.

One factor tends to restrict the practical use of forced air heat storage systems -- moving air feels cool and drafty unless its temperature is much higher than the room. To keep a room at 20 C, for instance, the standard forced air heating system typically

needs a temperature of 40 C or greater at the diffuser. Commonly, forced air heat storage systems cannot provide air at such a high temperature.

3. SYSTEM DESIGN

The objective in incorporating the heat storage bank in ER-1 was to study its effect on house temperature swings in the spring and fall seasons, and its cooling effect in the summer. It was assumed that the solar gains in the wintertime would be directly used in house heating.

A eutectic salt product, known as the HEAT TRAY, made by the Saskatchewan Minerals Corporation in Chaplin, Saskatchewan was installed in the heat bank. The HEAT TRAY is a sealed high-density polyethylene tray filled with Glauber's salt ($Na_2SO_4 \cdot 10H_2O$). This salt is derived from sodium sulphate found in certain lakes in Saskatchewan. When the tray is heated above 20 C, the salt changes phase from a solid to a liquid and stores the heat. When the tray cools below 20 C, the energy is released. (This action is much like the melting and freezing of ice.)

A total of 447 HEAT TRAYs were placed in the basement of ER-1, in an insulated 2.9 m3 compartment 1 m high by 1.2 m deep by 2.4 m wide with an interior volume of 1.8 m3 (Figure 5.1). The heat storage bank was charged with warm air from the ceiling area of the house. The moderated air was then blown through ducts back to the house by the air recirculating fan.

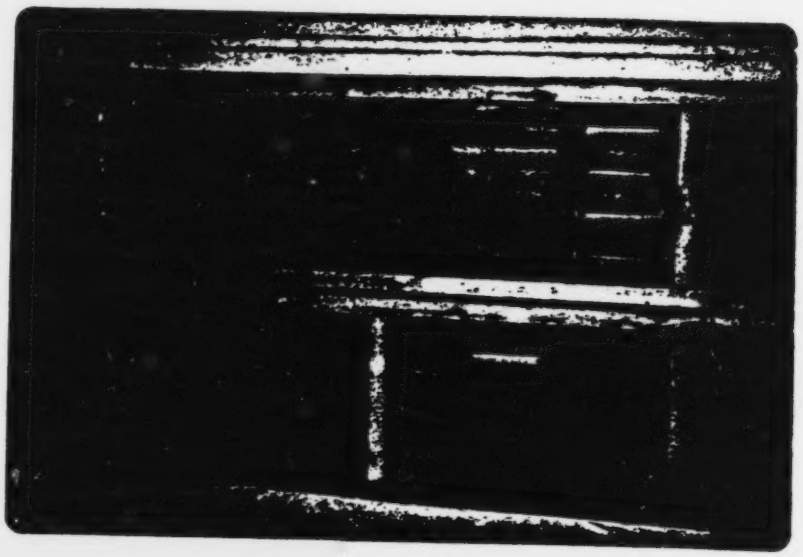

Figure 5.1 HEAT TRAYs stacked in the heat storage bank

A pair of motorized dampers controlled the direction of air flow through the compartment (Figure 5.2). In cooling mode, the air was drawn into the upper section of the heat bank around the trays and out the lower section. In heating mode the air flow was reversed. The length of air path through the trays was 5.4 metres.

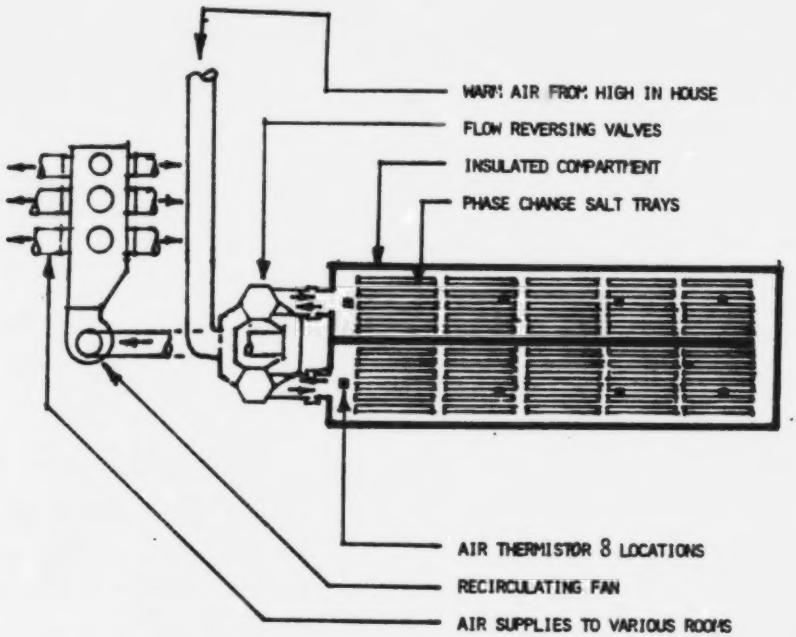

Figure 5.2 Mechanical connections to the heat storage bank

The latent heat storage capacity of the trays is 315 kJ each, a total of 140 MJ for the system. In addition, the trays have a mass of 3.5 kg each (1565 kg total for the heat storage bank) and can store half as much sensible heat as water. Table 5.1 compares the heat storage characteristics of the HEAT TRAY with water, for a storage system of similar mass.

Table 5.1
Comparison of the heat storage capacity of the HEAT TRAY and water

For a heat storage bank of 1565 kg, operating between 16 C and 26 C:	HEAT TRAY	water
Sensible heat storage capacity	3.3 MJ/C	6.6 MJ/C
Latent heat storage capacity at 20 C	140 MJ	0 MJ
Total heat storage capacity	173 MJ	66 MJ

4. ASSESSMENT TECHNIQUES

To assess the performance of the heat bank, six thermistors were installed at equal intervals throught the internal air path, and two at the air inlet/outlet points. These were scanned by the monitoring system every 30 seconds when the air recirculating fan was in operation.

5. PRELIMINARY RESULTS AND DISCUSSION

Only the practical aspects of the heat storage bank were evaluated in this project. Although the heat bank did function well for cooling, there were problems in heat storage. Further evaluation is needed on its effect on house temperature reponse, the temperature required for phase change, and the total volumetric heat storage capacity (see also Lange, 1983).

With the heat storage bank releasing heat at 20 C or less, the exiting air always felt cool at the diffuser. This was, of course, very acceptable in the hot days of summer, but only then.

The air direction dampers leaked around their edges and allowed some air to short-circuit the salt trays. This was corrected with the application of vinyl adhesive weatherstrip.

The air recirculating fan operated when cooling or heating was required. Typically the temperature drop across the bank was 2 to 3 degrees. In one test of the system, the recirculating fan was run for a whole month, which brought the temperature of the salts up to 21 C. The air at the duct vents, though at room temperature, still felt cool because it was moving.

Energy consumption of fans in heat storage systems should be closely evaluated. The power requirements of the fan in ER-1 were 260 W, or 22.5 MJ per day in continuous operation. This parasitic power drain alone equalled one half of the hot water heating energy, and could significantly affect system economics.

No economic analysis was calculated for the heat storage bank because it effectively performed an air-conditioning function. Such a function is considered a luxury and would not otherwise have had an analysis. The installed cost of such a heat storage system is estimated at $2500 (in 1981). Its operating costs are very small, less than $10 per month. In comparison, an air-conditioning system would have a similar installed cost, but costs tens of dollars per month to operate.

For further information on these systems, the reader is encouraged to refer to Lange (1983).

CHAPTER 6. EFFECTIVENESS OF THE TRIPLE-GLAZED WINDOWS

1. SUMMARY

The triple-glazed windows were assessed for effectiveness in reducing condensation, glare and nighttime window heat loss. Condensation and some frosting did occur on the lower edge of the windows at extreme temperatures, but did not cause problems. Considering the alternatives, triple glazing was considered the most practical window treatment.

2. BACKGROUND

Good window design is important in reducing heating costs. Such a design incorporates unbroken caulking and weatherseals, thermal breaks in the frame, and 13 mm spacing between the glazing layers.

The number of glazing layers appropriate for the Alberta climate is still in question. Double glazing is used most commonly, although triple glazing is becoming more widely accepted. Quadruple glazing is also appearing.

Triple glazing provides both advantages and disadvantages compared to double glazing.

Advantages:

- higher resistance to condensation,
- lower heat loss rate,
- lower heat gains in the summer,
- decreased glare and fabric fading due to higher solar absorption and reflection.

Disadvantages:

- lower daylighting levels,
- lower heat gains in the winter,
- higher cost.

Though window shutters can provide many advantages, the technology needs further development in Albert's climate. Resistance to snow and ice build-up, and simple effective inside operation is still a concern with exterior shutters. Interior shutters can have problems in sealing against condensation and dealing with decorative objects and plants on window ledges.

3. SYSTEM DESIGN

The objective in choosing the window design was to reduce heat losses in the most practical way. Triple glazing was chosen because of its thermal advantages and its higher resistance to condensation. Loewen windows were installed because of their wood frames and general quality of construction.

4. ASSESSMENT TECHNIQUES

The effectiveness of the windows was assessed by:

a) observing the presence of condensation,
b) calculating the window's thermal performance, and
c) determining the extra costs.

Refer to Chapter 5 for details on measuring the solar transmission factors of the windows.

5. PRELIMINARY RESULTS AND DISCUSSION

A. Window Condensation

Condensation began to appear on the windows whenever the outdoor air temperature fell below approximately -10 C with the indoor relative humidity over 40%. The condensation took the form of small drops of water on the bottom 20 mm of the glass. The glass temperature was lower at that location, for two reasons:

- the metal glazing separator acted as a thermal bridge,
- warm house air currents tended to be restricted because the window was recessed into the wall.

As the outdoor temperature fell further, more drops appeared. Below -20 C, some ice began to form at the lower corners. At -25 C, a 10 mm high, 3 mm layer thick layer of ice formed along the bottom edge of the glass. An example of this is shown in Figure 6.1. At times, a thin layer of frost appeared on the surface of the ice.

When the outdoor temperatures rose, the condensation and ice began to melt. The melt water generally stayed on the window frame and evaporated into the air. In the air-lock entrance, where the room temperature was a few degrees cooler than the rest of the house and the ice build-up somewhat greater, the melt water would occasionally run onto the window extension and evaporate. Never did the water run down the walls, or leave a stain.

When the outdoor temperature was lower than -20 C, a fine mist was observed on the upper floor windows after the shower was used. The fresh-air heat exchanger, which is controlled

automatically by the humidistat, usually ran for an hour afterwards, and the mist evaporated.

Small amounts of mildew appeared on the lower corners and seals of all the window frames where condensation formed in the winter. The upper floor windows also had larger quantities of mildew on the operating mechanism and seals. Mildew appeared at these places because moisture had been driven through the seals in the winter by the stack effect, whereupon it condensed on the cold surfaces.

Although evident, this condensation and mildew did not appear to present a problem.

B. Thermal Performance of Windows

Due to the large variability in the weather from year to year, only long term weather data is of practical use in assessing the thermal performance characteristics of windows. For this reason, the data published by Barakat (1980) is cited.

Table 6.1 and 6.2, excerpted from Barakat (1980), lists the monthly solar gains and transmission factors for double and triple-glazed, south-facing windows. Over the heating season, triple-glazed windows have a net energy gain 350 MJ/m2 greater than double-glazed windows. On ER-1 with 15.2 m2 of south facing triple-glazed windows, the total difference in gain is 15.2 x 350 or 5.3 GJ. This is equivalent to $65 in avoided electric space heating costs. (The forest shading was ignored in this calculation, although since shading reduces the gain, the net effect of triple glazing increases.)

Note also in Tables 6.1 and 6.2 that the solar gain and thus indoor light levels are less with triple glazing. This reduces glare and fabric fading noticeably. The difference in cooling energy required throughout the summer is essentially negligible.

Similar tables for other directions were calculated by Barakat (1980). Table 6.3 lists the savings in space heating costs of triple glazing over double glazing for ER-1. The total savings amount to $84 per year at 1981 energy prices.

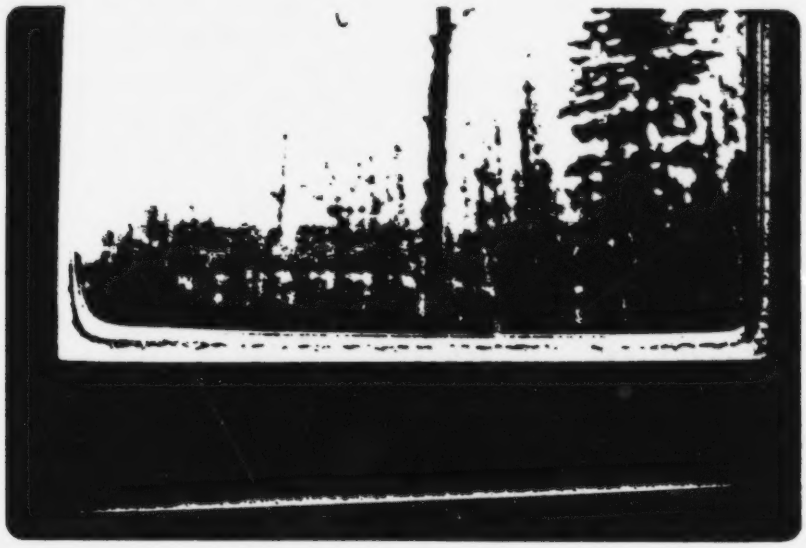

Figure 6.1 Condensation on windows at -25 C

Table 6.1
Solar gains through south-facing double-glazed windows

	Transmission factor	Solar gain (MJ/m2·month)	Heat loss (MJ/m2·month)	Net gain (MJ/m2·month)
January	0.76	178	291	-113
February	0.75	297	204	93
March	0.73	450	222	228
April	0.71	376	135	241
May	0.68	275	67	207
June	0.67	177	58	119
July	0.68	262	49	213
August	0.70	316	36	280
September	0.73	314	91	223
October	0.75	300	145	155
November	0.76	197	223	-26
December	0.77	197	287	-91
Heating season total (October to April):		1993	1507	486
Cooling season total (May to September):		1344	301	1043

Table 6.2
Solar gains through south-facing triple-glazed windows

	Transmission factor	Solar gain (MJ/m2·month)	Heat loss (MJ/m2·month)	Net gain (MJ/m2·month)
January	0.70	164	190	-26
February	0.69	273	135	138
March	0.67	413	147	266
April	0.65	344	90	254
May	0.62	250	45	205
June	0.61	161	39	122
July	0.61	238	33	205
August	0.64	289	24	265
September	0.67	288	61	227
October	0.69	276	97	179
November	0.70	181	148	34
December	0.70	181	189	-8
Heating season total (October to April):		1832	996	836
Cooling season total (May to September):		1226	202	1024

Table 6.3
Summary of the energy savings of triple-glazing over double-glazing on ER-1, over the heating season

Direction	Window area (m2)	Net energy savings (MJ/m2)	Equivalent electricity savings ($)
South	15.2	350	65
East	2.1	419	11
West	1.2	417	6
North	0.3	462	2
TOTAL	18.8	6840 MJ	$84

C. Extra Costs

The extra cost of the triple-glazed windows was $1000 or 15%. The extra cost fraction depends on the size and complexity of the window.

The value of triple-glazed windows includes the comfort value as well as the energy savings (see also Chapter 11). Economic calculations on the energy savings alone show the

$$\text{simple return on invesment} = \frac{84}{1000} = 8.4\%.$$

The payback for this return is 12 years, based upon the cost of providing space heat by electricity.

The present alternative to triple glazing is double glazing, which presents poorer health and comfort standards in the house environment, because lower humidity levels must then be maintained to control window condensation. Triple glazing appears to be the best window treatment. Its payback period of twelve years shows that, even today, it a good value.

CHAPTER 7. FRESH AIR HEAT EXCHANGER

1. SUMMARY

A fresh-air heat exchanger was installed in ER-1 to control humidity levels, indoor air quality and recover heat from waste house air. The practical aspects of the air exchanger were studied. The unit worked well, with no observed frosting problems.

2. BACKGROUND

Air tightness and the control of unwanted air infiltration is common in all energy efficient houses today. At some point in the reduction of air infiltration, ventilation must be supplied by mechanical means. NRC recommends mechanical ventilation when the house is tested to have an air change rate of less than 1.5 per hour under a 50 Pascal pressure difference across the envelope. ER-1 was tested to have a pressurized air change rate of 1.09 (see also Chapter 10).

One of the first practical fresh-air heat exchangers for residential use was designed by Dr. Bob Besant at the Mechanical Engineering Department of the University of Saskatchewan in Saskatoon (Besant et al., 1987). His design used polyethylene film and plywood, and could be home-made for $200 including fans. Since then a rapidly growing air exchanger industry has sprung up across North America with manufacturers in many locations including Saskatoon, Regina, Toronto, Winnipeg, and New York State.

These air exchangers have a typical effectiveness of 70% to 80% (Van Ee, 1981). They cost $800 to $1200 to purchase, $200 to $300 to build at home. Installation of an air exchanger costs between $300 and $600 (complete with extra ductwork).

3. SYSTEM DESIGN

The fresh-air heat exchanger in ER-1 was installed to provide air quality control. It ventilated the house and removed stale air, excess moisture and odours. At the same time, heat was recovered from the stale air to pre-heat the incoming fresh air (Figure 7.1).

The air exchanger used in ER-1 was made by Enercon Industries in Regina (Figure 7.2). It consisted of concentric cylinders of a thin plastic film with stale and fresh air flow paths in alternating layers. Layer separation was approximately 8 mm. This large separation resisted blockage of air channels due to frost build-up.

The electric clothes dryer in ER-1 was connected directly to the air exchanger since this is an excellent source of heat to warm incoming air. A small filter was installed in the air duct from the clothes dryer to remove any lint. There is some question as to whether such a connection meets the Alberta Building Code. Such a connection with a gas-fired dryer is not recommended.

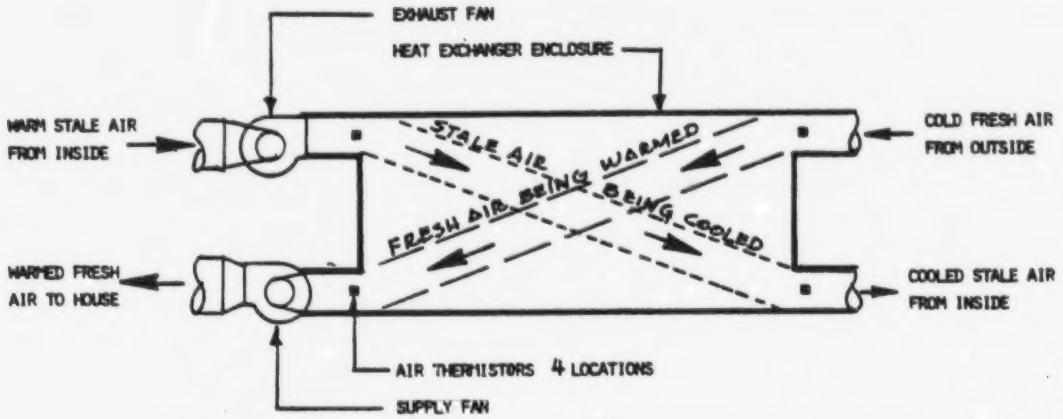

Figure 7.1 Fresh-air heat exchanger schematic

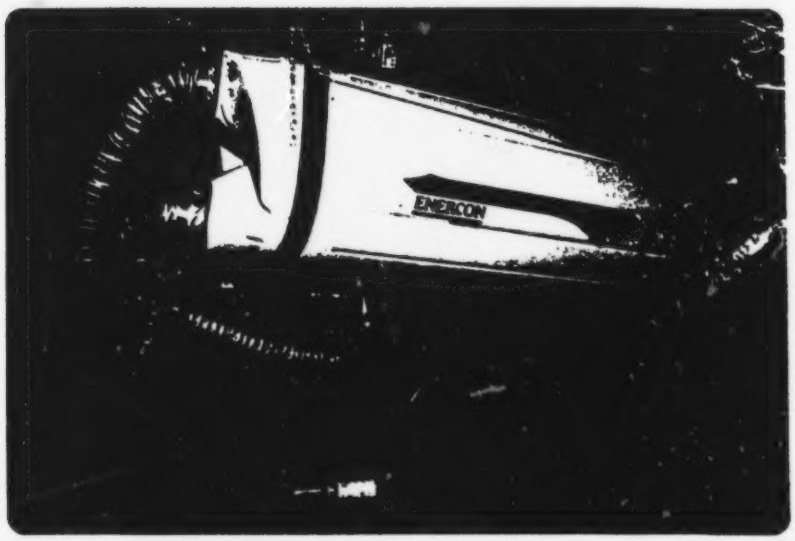

Figure 7.2 The fresh-air heat exchanger installed

The air exchanger was operated automatically by a humidistat, by the clothes dryer, and two bathroom fans. The humidistat was used in the same way as a thermostat. The maximum humidity level was set and the air exchanger automatically turned on if the level rose higher. (See Chapter 10 on air quality control.)

The maximum air flow rate through the exchanger was 100 l/s. This rate could change the total air volume in the house every 90 minutes.

4. ASSESSMENT TECHNIQUES

To assess the performance of the air exchanger, thermistors were installed at the air inlet and outlet ports (Figure 7.3). The thermistors were scanned by the electronic monitoring system every thirty seconds when the air exchanger was in operation.

In addition, relative humidity measurements were taken using a sling psychrometer.

Figure 7.3 Thermistor connections on the exchanger

5. PRELIMINARY RESULTS AND DISCUSSION

During the winter, the air exchanger controlled the humidity levels very well, keeping them reduced to the 40% to 50% range. The exchanger typically operated for an hour after the shower was used, and occasionally when cooking dinner. When guests were present, the exchanger operated more frequently, presumably due to a slight rise in the humidity level caused by additional moisture from the respiration of the guests.

Condensation and light frost occurred at the stale air outlet port of the exchanger during the winter. Heavy layers of frost were never observed because the irregular cycle of operation provided natural defrosting. A small hose carried the condensed water from the outlet port to a floor drain.

In the winter, after conditions of rime build-up (similar to hoar frost) on trees around the house, a thin layer of rime was also observed on the exterior air intake and outlet grills. The rime plugged the inlet solid, and had to be scrapped away.

A few suggestions can be made regarding the installation of the air exchanger:

- Keep the lines to the inlet and outlet ports as short as practical, to reduce the amount of insulated ducting required.
- Place the inlet and outlet ports at least 2 metres apart to prevent short-circuiting.
- Do not place the outdoor inlet and outlet ducts close to grade level as snow build-up can cause obstruction.
- Incorporate a hood on the inlet and outlet ducts to resist rime build-up.

There is some question as to whether the air exchanger core should be cleaned regularly to prevent bacteria and fungus build-up. Some exchanger brands allow for ready cleaning of the core, some are extremely difficult to clean. The Enercon unit in ER-1 is hung from the ceiling on straps, and can be readily dismounted to be cleaned with a hose. After two years of operation without cleaning, no visible problems have been noticed.

No vibrations or other mechanical problems have been noticed with the Enercon unit either.

During the coldest months of the year, the air entering the house from the air exchanger may be too cool to be ducted directly into the living space, and should instead be directed into a buffer zone such as a hallway, basement, or cold air return on a forced air system. This suggestion should be particularly noted in the design of houses where wood stoves, radiant floor heating or electric baseboard heaters are installed instead of forced air systems.

The incoming air temperature may be found from the exchanger effectiveness equation:

$$Tfa = e\ (Th - To) + To$$

where Tfa is the warmed fresh air entering the house from the exchanger,
To is the outdoor temperature,
Th is the warm stale house air, and
e is the air exchanger effectiveness fraction.

In extremely cold weather, if the effectiveness, e, is 70%, the outdoor temperature is -40 C (To), the house temperature is 21 C (Th), then the Tfa, (the air entering the house) will be only 3 C. For average January conditions, Tfa would be 10 C.

For more information on the performance of fresh-air heat exchangers, the reader is encouraged to refer to the report by Fisk and Turiel (1982).

CHAPTER 8. GREY-WATER HEAT EXCHANGER

1. SUMMARY

A grey-water heat exchanger was installed in ER-1 to recover heat from waste grey water and to pre-heat incoming potable water. The unit increased the water temperature by an annual average of 7 C. Control of scum and odour were judged to be acceptable by the occupants.

2. BACKGROUND

Recovering heat from waste water can decrease heating costs. Dumont and Besant (1978) described various types of grey-water heat exchangers including the one in the Saskatchewan Consevation House.

The term 'grey water' describes waste water draining from bathtubs, sinks, dishwashers, and clothes washers. This should not be confused with sewage, which is called black water.

The simplest method of recovering heat from grey water is to allow the cool incoming water to sit in a tank surrounded by the warm waste water. The heat is then transmitted by convection and conduction towards the cool fluid. Much more efficient designs incorporate fins which transmit the heat deep into the volume of the fluids. Industrial designs maximize the heat transfer area between the fluids by the use of fins and small diameter tubes.

3. SYSTEM DESIGN

The objective in designing the grey-water heat exchanger was to make it economically worthwhile, keeping it simple and utilizing commonly available materials. The grey-water exchanger used in ER-1 consisted of a 160 litre cylindrical galvanized pressure tank placed horizontally inside a 700 litre open holding tank (Figure 8.1). The system was located in the basement.

Grey water enters the holding tank just below the water line. It automatically overflows from a bottom outlet through a standpipe to the sewer line (Figure 8.2). Under demand, the potable water passes through the cylindrical tank of the heat exchanger and on to the house water system.

Possible cross contamination is avoided because the potable water is under pressure, and the grey water is not. Any leak would cause water to flow to the grey water side.

All the potable water coming into the house, except for the cold tap in the kitchen, first passes through the grey-water exchanger.

The water was routed in this way for two reasons: to keep the plumbing system simple, and to reduce the amount of hot water used. Because the cold water entering the shower is tempered, less hot is needed to achieve the same shower temperature.

The grey water from the kitchen sink was not directed through the exchanger because of the high amount of fat and particulates. The hot waste water from the dishwasher does not go through the grey-water exchanger also because of the particulates, and because of the needs of the septic tank. The District Agriculturalist advised that if too much heat was taken from the waste water, the bacterial action in the septic tank might suffer in the wintertime.

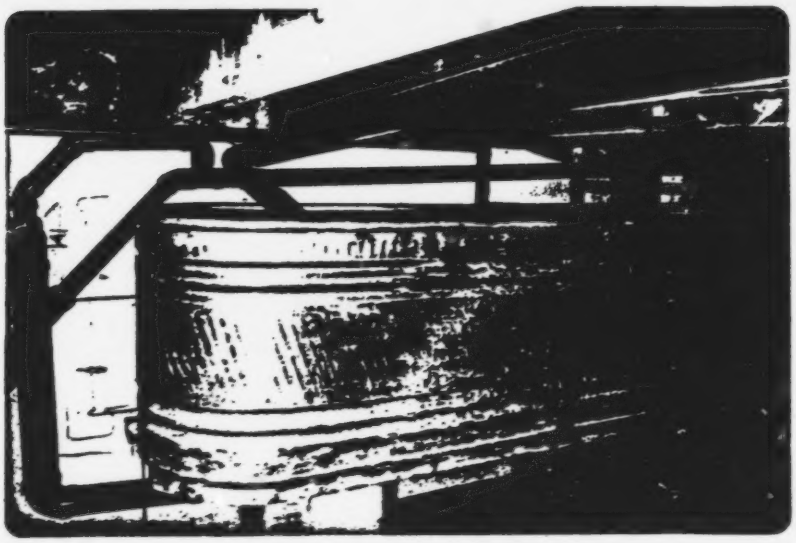

Figure 8.1 The grey-water heat exchanger

4. ASSESSMENT TECHNIQUES

To assess the performance of the grey-water heat exchanger, thermistors were placed in the incoming and exiting potable water, and grey water lines. In addition, a flow meter with a one litre resolution was used to provide flow rate information to the electronic monitoring system.

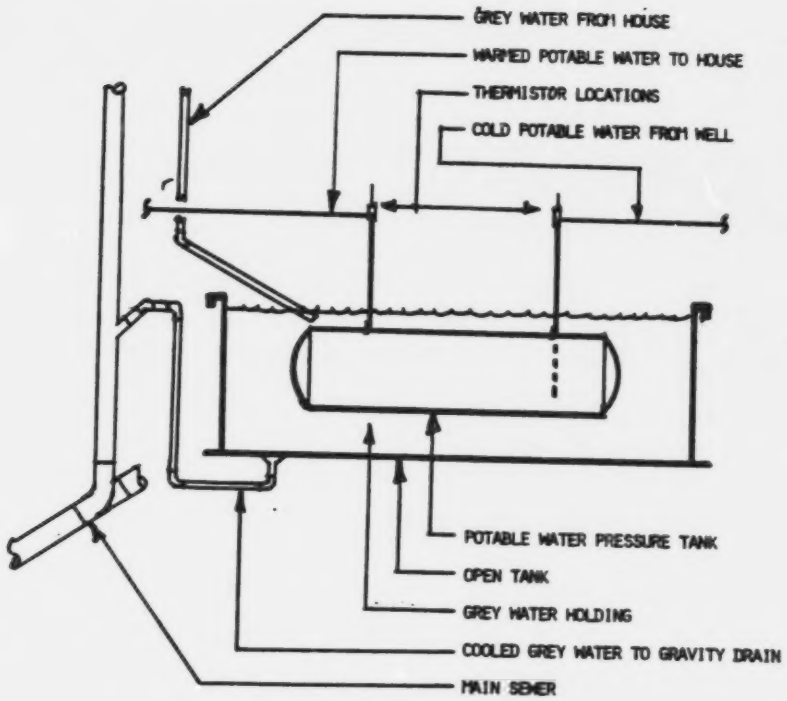

Figure 8.2 Schematic of the grey-water heat exchanger

5. PRELIMINARY RESULTS AND DISCUSSION

The grey-water heat exchanger raised the temperature of the incoming potable water by an annual average of 7 C. This value varied from 4 C in the winter to 10 C in the summer. On an annual basis, this represented 14% of the water heating requirements.

A ring of scum did develop around the water line of the holding tank. It appeared to consist of fibres from the clothes washer and hair from the shower. Although it continued to build up slightly, it did not present a problem. A 5mm layer of particulates built up on the top of the immersed pressure tank. A once yearly brushing of the tank would be recommended to maintain efficient heat transfer.

A slight, inoffensive scent from the open top of the holding tank was noticed in the basement at infrequent times. It was not noticeable in the rest of the house and was not a problem to the occupants.

The cost of the grey-water heat exchanger was $300 installed. The components were readily available and easy to assemble.

The following example illustrates the economics of the grey-water exchanger:

Assuming:

a hot water consumption of 185 l/day,
an incoming temperature of 10 C,
a hot water temperature of 60 C,
a temperature rise of 7 C, and
an electricity price of 12.13 $/GJ,

then:

The annual cost of electric water heating without the heat exchanger (excluding standby losses) = $170.

The savings fraction is 7 C /(60 C - 10 C) = 14%

The dollar savings is 14 x 170 / 100 = $24.

The simple rate-of-return is $300 / $24 = 8%

The simple payback is $24 / $300 = 13 years.

One additional factor which has not been fully evaluated is the hot water savings due to the use of tempered cool water. Initial estimates indicate that this would increase the savings fraction from 14% to about 16%.

CHAPTER 9. USE OF THE WOOD BURNING STOVE

1. SUMMARY

A wood stove was installed in ER-1 to function as a primary wintertime heat source, emergency cook stove, and cosy fireplace. Cost savings, comfort, appearance, operation and general interest were considered in the assessment of the stove. Actual savings on space heating costs were $240 the first year for ER-1. Operation was not difficult, but did require some personal effort.

2. BACKGROUND

Standard fireplaces are becoming known as inefficient heaters (Cheremisinoff, 1980). Glass doors, recirculating air fans, and outside combustion air intakes are being added to increase the efficiency. Because of their higher efficiency, wood stoves are becoming common as a substitute for fireplaces. In some areas of the continent, most notably the Maritimes, Quebec, New England states, and the Pacific North-West, wood heating is very popular.

Wood heating has brought with it a burgeoning wood stove manufacturing industry. Hundreds of wood stoves are now available, from the very cheap ones made in Taiwan, to the high quality stoves of Vermont, Washington, and Norway (Flagler, 1979). Claims of manufacturers extoll secondary combustion air inlets, thermostatically controlled combustion, high heat storage mass, and pre-heated combustion air (Flager, 1979, pg. 21).

With the realization of possible air pollution from wood stoves, many are now equipped with catalytic converters which continue the burning of flue gasses and increase combustion efficiency.

Wood heating can be very practical in houses that require very little heating. Where the minute amount of natural gas used does not justify the cost of natural gas service, and wood in some form is available, heating costs can be kept at a minimum.

3. SYSTEM DESIGN

The requirement in choosing the supplementary heating system for ER-1 was that it be useable for multiple purposes and have pleasing aesthetic qualities.

The Cawley 800, a cast iron air-tight wood stove, was chosen. It was made in Pennsylvania and measures 685 mm wide x 660 mm high x 510 mm deep. Two spin draft dampers control combustion air ducted directly from the outside by a hidden pipe. The stove is

connected to a 200 mm single wall flue, 6 metres long. It has an optional screen for open fire viewing, and two cooklids for emergency cooking should the electricity be off (Figure 9.1).

The wood stove was placed within a brick alcove on a tile hearth in the living room with a wood storage area on one side. A 250 mm diameter wood port near the stove allows the wood storage area to be filled directly from the outside without having shavings tracked through the house (Figure 9.2).

Figure 9.1 The wood stove in a fireplace setting

4. ASSESSMENT TECHNIQUES

In assessing the value of the wood stove, the following parameters were considered:

a) cost savings and extra costs,
b) handling the wood,
c) starting, tending and banking the fire,
d) handling the ashes,
e) heating effectiveness, and
f) compatibility with decor.

Figure 9.2 The wood storage shed and wood port into the house

5. PRELIMINARY RESULTS AND DISCUSSION

A. Cost Savings and Extra Costs

The cost of wood depends on the source and its proximity to the residence. Stove wood is readily available on the market for $10 - $30/m3 ($30 - $110 per cord) for poplar, and $30 - $40/m3 ($110 - $150) for birch. Scrap fir is available for $4/m3 ($15 per cord). A private woodlot could net the lowest costs.

The thermal analysis of ER-1 in Appendix C shows space heating to use 20 GJ of energy over an average climate year for an electricy cost of $245 in 1981 prices. By comparison, during the 1981/82 winter, approximately 6.7 m3 of wood was burned in the wood stove (Table 9.1), the equivalent of 21 GJ at 60% efficiency, for a cost of $11. This cost was kept low because most of the wood burned was from the site cleared in the forest for the house. A small amount of scrap fir was also purchased.

Table 9.1
Supplemental wood heating consumption in the 1981/82 winter

	Units	Fir	Poplar	Total
Service charge	$/m3	6 for transportation	0.20 for chain saw gas	
Price in 1981	$/m3	4	0	
Material consumption	m3	1	5.7	6.7
Energy density	GJ/m3	7	5	
Heating efficiency	%	60	60	
Net energy consumption	GJ	4.2	17.1	21
Cost	$	10	1	11

NOTE: Heat energy from wood is very difficult to estimate. These are approximate values of actual wood heating consumption and costs. A total of 6.7 m3 (1.8 cords) of wood was used in the 1981/82 winter. Heating efficiency for air-tight stoves is in the 50% to 60% range.

A cost analysis of the wood stove was not considered, because the stove served of the purpose of the fireplace. Such analyses are not performed on fireplaces because they are high-demand luxury items. In addition, a wood stove:

- can be much less expensive than a fireplace,
- is far more efficient and effective in heating a house than a fireplace, and
- can have the same aesthetic appeal as a fireplace.

B. Handling the Wood

1) Obtaining the wood

The length of time to obtain the wood depends on the proximity of the source to the residence and the quantity required. For a low energy house, no more

than 11 m3 (3 cords) should be required on an average winter. Delivered wood requires only the time to stack it, possibly an hour or two. Wood from a private woodlot could take a family a couple of weekends to cut, split and stack. Flagler (1979) covers these details quite well in his book.

2) Bringing in the wood

It takes 20 minutes to fully load the wood storage area of ER-1 (with 0.6 m3 or 1/6 cord). One person stands on the inside of the wood port to stack the wood. Another person carries armsful from the stack and feeds in the pieces. Refilling the wood storage area is required weekly during the coldest part of the year, and less as the weather warms up. The wood is used as a heating supplement to some degree from mid-October to mid-April.

C. Starting, Tending and Banking the Fire

The ease with which the wood was ignited depended on the type of wood. Green poplar was extremely difficult to start and required some patience. (Green wood is not recommended.) Dry poplar, scrap wood, or lumber was easy to start with a bundle of newspapers. Building the fire took 5 to 10 minutes.

Bundles of scrap paper may have some potential for supplemental heating. The paper started easily and burned fiercely. The inner layers seemed to be insulated from burning and so burned incompletely. Scraps of burned paper floated up the chimney and sprinkled themselves over the roof and yard, depending on which way the wind was blowing. A screen on the chimney cap would have prevented this litter.

The fire did not need attention during the burn period. During the coldest days in the morning before work, or evening before retiring, the fire was banked up, the air dampers turned to low, and the stove left unattended. Burn periods could be extended to 7 or 8 hours without rekindling when operated in this manner. It was <u>never</u> necessary to restoke the fire in the middle of the night.

The draft for the fire was excellent, probably due to the 6 m long chimney. Sometimes a small amount of smoke drifted out through the open door when initially starting a fire. Occasionally the scent of wood smoke would be noticed in the house and outdoors.

D. Handling the Ashes and Mess

The production rate of ashes depends on the efficiency of the stove and the amount and type of wood burned. The Cawley 800

does not have a separate convenient ash pan. When burning green poplar or large amounts of paper, ashes were removed weekly at the peak of the heating season. The scrap lumber and dry wood produced far less ash, so removal was needed only every three weeks. Ash removal took 20 minutes and could be messy if care was not taken.

Some wood chips and pieces of char fell onto the hearth when tending the fire. A whisk was used to brush these off to one side. If this was not done each time, the area would begin to look messy.

Many warnings have been given about the hazards of chimney fires caused by creosote build-up (Flagler, 1979, pg.151). Chimney cleaning is recommended at least twice per winter, but depends on the manner in which the stove is operated. At the end of the heating season, the chimney on ER-1 had not been cleaned and had only a 5 mm layer of powdery soot at the top. This low level of soot may have been the result of a weekly hot cardboard fire which burned off small accumulations.

E. Heating Effectiveness

The manufacturer's specifications state that the Cawley 800 has a maximum heat output rate of 15 kW. This rate is more than double the house requirements at -40 C. Control of the heat was of greater concern than the amount of heat produced.

The spin draft dampers enabled some degree of control over the fire. A hot fire could not easily be stopped. Overstoking had to be watched closely when the outdoor temperature rose above -10 C or the house would easily reach 28 C and higher. Once the stove itself had absorbed heat, it would continue to re-radiate it throughout the night.

The morning warm-up time after extremely cold outdoor night temperatures varied. The upper floor would reach 19 C (from 16 C) within 20 minutes. The furthest rooms on the lower floor might take an hour.

F. Compatibility with Decor

The stove proved to be aesthetically appealing to guests and easy to live with for the residents. It would appear that a good quality wood stove in an attractive setting is a pleasant living room appliance.

Wood heating is dealt with in numerous publications. The Canadian Wood Heat Book (Flagler, 1979) is particularly good.

CHAPTER 10. EFFECTS OF A LIMITED AIR EXCHANGE RATE

1. SUMMARY

This project studied ER-1's limited air exchange rate and its effect on comfort, air quality and thermal performance. A pressure test determined the air infiltration rate to be 1.09 air changes per hour at 50 Pa, which is considered typical of air-tight houses. The fresh air heat exchanger easily controlled stale air, odour, and excess humidity.

2. BACKGROUND

Concern about home heating efficiency has caused the role of the air/vapour barrier to be re-examined. In the past, it was primarily used to prevent moisture from damageing envelope materials (CMHC, 1977). When properly constructed, it can also control the flow of air into or out of the house. Typically, one third of residential heating costs result from this air leakage, (known as air infiltration when air is leaking into the house, and air exfiltration when leaking out).

The strategy with regard to air change should be to lower the natural air infiltration rate to as low a value as practical for reasons of health and saving energy, and then to provide ventilation when required to ensure optimum air quality. A number of new products and construction techniques help achieve this stategy.

The air/vapour barrier is usually poorly treated during house construction. Thin 50 micrometre poltethylene sheeting, careless installation, poor construction details, the routing of wires through the envelope, and the trimming of mounted drywall contribute to numerous tears and holes. The resulting uncontrolled air and moisture flow increases heat losses, drafts, cold spots and air dryness.

The supply of fresh air to the house also controls build-up of noxious gases, odours, and stagnation. Gases, known as 'indoor pollutants', including radon gas from mineral based materials, urea formaldehyde from furniture and cabinet glues, paint solvents, and carbon dioxide and monoxide combustion products have been known in extreme circumstances to rise in concentration past saftey guidelines. The elimination of these gases in air-tight houses can be easily handled by a controlled ventilation system (see Chapter 7).

Typically in Alberta, the home atmosphere is very dry in the winter (10% to 20% RH), requiring a supplement to the humidity produced by household activities. A tight air/vapour barrier

usually reduces the air moisture loss to such a degree that no additional humidification is needed (Hughes, 1982). The high humidity levels can reduce the severity of certain respiratory illnesses (Green, 1979, 1982).

Older houses often had air infiltration rates exceeding 1 change of air per hour. Newer houses are being built, in standard fashion, that achieve rates of 0.5 to 0.65, although some have been measured as low as 0.3. The new low energy designs typically reach as low as 0.05 (Ener-Corp, 1982).

3. SYSTEM DESIGN

The objective in installing the air/vapour barrier on ER-1 was to achieve a very low infiltration rate, and to gain operational experience in living in a well-sealed house. A fresh-air heat exchanger was installed to provide humidity and air quality control (see Chapter 7).

A 135 micrometre thick polyethylene film was used for the barrier, and then sealed with acoustic sealant (see Chapter 3). Care was taken whenever possible to ensure a solid backing at adjioning sheets, to prevent wind from damaging the seal (University of Saskatchewan, 1981).

Poly vapour hats did not have to be used on the outside-wall electrical boxes because the 2x3 ribbons provided a space between the air/vapour barrier and the drywall in which to place the boxes and run the wires. No electrcal fixtures were installed in the ceiling. Where a few wires did penetrate the air/vapour barrier for garage wiring and exterior fixtures, a polyethylene flap was fashioned to seal the puncture.

4. ASSESSMENT TECHNIQUES

The effects of a limited air exchange rate were assessed through observations and a pressure test.

The occupants observed humidity, odour, and air quality characteristics under several conditions in winter and summer including social evenings and gatherings, and low occupancy levels.

A pressure test determined the house air exchange rate under pressurized conditions. This test is very useful in estimating the integrity of air/vapour barriers, and evaluating design and installation practices. The test pressurizes the house to 250 Pa and then at decreasing pressure levels obtains air flow readings from the house through a calibrated air nozzle. An air exchange rate is then calculated for a pressure of 50 Pa.

5. PRELIMINARY RESULTS AND DISCUSSION

The pressure test measured the house air exchange rate to be 1.09 changes per hour a 50 Pa. This value equalls an infiltration rate of 0.06 air changes per hour under average natural conditions (Harold Orr, personal communication), and is considered quite good for such a house, though it is not the lowest that has been achieved in the industry.

The occupants observed infrequent stuffiness of the air, although lingering odours were not noticed.

Energy efficient, quick, and thorough air exchange can be provided by manually turning on the air exchanger and the air recirculating system fan (through remote switches in the dining room). This rapid addition of fresh air was especially convenient on occasion when cooking or when the house required airing in the winter. The total house air could be replaced in 90 minutes by the air exchanger. In the summertime, ventilation using the windows and the thermo-syphoning effect (caused by the height of the house), provided effective ventilation.

The heat exchanger was installed to operate on demand by the humidistat, and not continuously at low speed as recommended by the manufacturer. At times, therefore, the house had a very low air exchange rate, such as on a winter night. The occupants felt that at such times the air change rate was too low.

From observations of the effects of the low air change rate, it is recommended that:

1) fresh air heat exchangers be installed to operate continuously at low speed in the wintertime as per manufacturer's instructions, and
2) a further study of the quality of the air under these low air exchange rate conditions be undertaken.

As reported in Chapter 3, the humidity was high, and supplemental humidification was never needed. The humidity level was usually between 40% and 50%. A low of 30% was recorded when the outdoor air temperature was at -40 C.

CHAPTER 11. ECONOMICS AND CONCLUSIONS

1. SUMMARY

The costs, benefits, and inconveniences of the energy-saving measures on ER-1 were assessed and compared. Total net costs were $3400. The first-year investment return was 25%, for a simple payback period of 4 years. The contribution of energy conservation to the heating requirements was calculated to be 59%, which illustrates the emphasis that should be placed on low-energy housing.

2. BACKGROUND

In the assessment of system performance factors, it is typically assumed that the worth of the system will be judged on the "bottom line" of costs and benefits of conservation and solar energy systems.

Economic indicators such as payback period, net present value and return on investment give an idea of value to a homeowner. Other factors such as aesthetics, however, must be considered since it is aesthetic reasons and not economic ones which commonly justify the installation of such items as fireplaces and bay windows in standard houses. Comfort levels. health benefits, and aesthetic qualities, therefore, should also play a role in assessing and justifying conservation and solar systems.

In the planning of low-energy homes, designs and costs of systems must be optimized, and the systems that become redundant because of the energy-saving measures, eliminated. For example, a home incorporating super-insulation and air-tightness does not require the large-sized furnace typically installed in a standard home.

Energy-saving measures incorporated in a house compete with each other for maximum benefits. While measures may be assessed separately, their combined effect will not be the total of the individual assessments. One must therefore consider the combined measures in order to arrive at an accurate assessment.

Consider the following illustration of the above competition:

> Energy is wasted in heating a house because of the inefficiency of furnace A. The more energy the house needs, the more energy furnace A has to supply and consequently, the more it has to waste.
>
> If a furnace of greater efficiency (furnace B) was installed, it would have a certain return on its

investment coming from the lesser amount of fuel it wastes. The house requires the same amount of heat, but furnace B would not waste as much fuel as furnace A in supplying it.

If extra insulation were added to the house, the house's heat energy requirements would be reduced. Since furnace B would not have to supply as much heat, it would then waste less fuel. Its higher efficiency would therefore be of less value. (In a typical house with an $800 per year heating bill, a standard 65% efficient furnace might waste $200. This amount is the maximum that a more energy efficient furnace could save in such a situation. In a low-energy house with a heating bill of $300, the same standard furnace would waste only $30.)

Similar examples can show this type of a competition between all energy conserving measures including insulation, air-tightness, heating system efficiency, night-setback thermostats and solar heating systems.

Two other factors affecting house economics are the cost of domestic water heating and the relative cost of energy supply options. In looking at the economics of energy options, it is typically only the cost of space heating that is considered. The cost implications of water heating are often overlooked.

In conclusion, to realize both an economically and technically optimized design, a sound understanding of the engineering principles of conservation and solar energy is required. This requirement has not yet been given an adequately widespread emphasis by the design or building industry.

3. ASSESSMENT TECHNIQUES

The following three principles govern the economic assessment of ER-1:

1. comfort, health and aesthetic factors were included,
2. features not relevant to the economics under assessment were not considered,
3. the energy saving measures on ER-1 were analysed as a group, thus avoiding errors caused by the effects of competition.

In effect, grouping the measures into one analysis directs the savings from the high return-on-investment (ROI) measures towards the measures which by themselves may have a less favourable ROI.

Simple ROI and and payback were the only economic indicators used in the assessment. These indicators apply primarily to residences

that are not income producing buildings. Other factors should be assessed, though, including monthly mortgage payments and utility charges. (These factors fall beyond the scope of this report and are not included here.)

4. PRELIMINARY RESULTS AND DISCUSSION

A. Economic values

The cost of the first year's heating using a combination of wood and electricity ($161) was discussed in part D of Chapter 3. The average annual heating costs using only electricity ($389) are shown in Appendix C, Table 7. As can be seen, the first year heating costs are significantly reduced from the $625 per year of the standard comparison house (Appendix D, Table 7).

The phrase "standard comparison house" is used here to describe a house with dimensions similar to ER-1 but constructed using standard levels of energy conservation. The performance analysis of this comparison house is included as Appendix D. To simplify the analysis in this report, the savings due to the domestic water pre-heating systems of ER-1 have also been included in the standard comparison house.

Table 11.1 illustrates a simple economic analysis of the energy-saving measures employed in ER-1 relative to the standard comparison house, and shows the value of three common heating fuels. As recommended above, the analysis includes the value of comfort, health and aesthetic factors. To assess these factors on a common basis, they are expressed as a personal value (in dollars), and include both benefits and possible inconveniences. By assessing the factors as a personal value, in effect a question is being asked: "How much is it worth to you per year to have the benefits of this design? (and put up with or avoid possible inconveniences?)". This question can and should be asked when assessing standard housing design as well.

The personal value placed on the benefits and inconveniences has a significant effect on the analysis. To cite an extreme example, if the personal value of saving $600 per year in energy is worth nothing to someone or worth nothing in a marketing strategy to a developer, then there is probably no interest, in that instance, in measures to save energy!

From Table 11.1, the assessment, based on the personal values of the occupants, shows that for the investment in this house the occupants received $850 in value the first year which is a 25% return on their investment.

Under the present economic conditions, this 25% return is better than money in the bank. Since the return-on-investment indicator provides the bottomline to the assessment, it is an appropriate way to state the results.

B. Contribution of energy sources to space heating needs

All energy crossing the house envelope and entering into the house serves to supply the heating needs. This energy includes heat from:

- sunshine entering through windows,
- domestic electricity used in appliances,
- normal occupant activity,
- fossil fuels burned in a furnace, and
- wood or paper burned in a wood stove or fireplace.

The heat gains from domestic electricity consumption and occupant activity are referred to as domestic activity gains. This heat is generated because the residence is occupied.

Table 9 in Appendix C summarizes the fraction of ER-1's heating requirements that are supplied by each of its energy sources. It is seen that solar energy supplies 42% of the heating requirements. This solar fraction cannot be applied directly to other house designs, however. Table 9 in Appendix D summarizes the heating requirements for the standard comparison house. Note, for instance, that the solar gain in that house only supplies 20% of the total requirement.

Table 11.2 summarizes the contribution that ER-1's energy sources make (including conservation), relative to the space heating needs of the standard comparison house. This data is taken from Appendices C and D, Table 9.

Table 11.2 reflects the mix of conservation and solar energy that is appropriate for housing in northern climates. In showing that energy conservation effectively supplies 59% of ER-1's heating requirements, this data supports the effort placed on energy conservation by the advocates of low-energy housing.

It also illustrates the important role of solar heating once the use of energy has been controlled. Of the gross supplemental space heating required, solar supplies 62%.

With many low-energy house designs, the net required heating supplement is so low that innovative heating systems become appropriate. Such systems already in use in many houses include using coils placed in the domestic water heater to supply space heating, wood stoves, active solar thermal collectors, or small electric baseboard or in-duct heaters.

Table 11.1 Simple economic analysis of the measures to reduce space heating costs

Source of energy:		Wood	Electricity	Natural gas
Initial costs ($)				
1. Total extra cost	$ TEC	7200	7200	6550
2. Total cost reductions	$ TCR	3800	3800	800
Net Increased Cost: (TEC-TCR)	$ NIC	3400	3400	5750(1)
Personal value of inconveniences ($/year)				
1. Handling of firewood	$ a	50	0	0
2. Glare from sun	$ b	0	0	0
3. Fading of fabrics	$ c	0	0	0
4. Poor air quality	$ d	0	0	0
5. Imprecise temperature control				
- overheating from wood stove	$ e	50	0	0
- cool mornings in winter	$ f	50	0	0
6. Other?	$ g	0	0	0
Total Inconvenience Value: (a+b+c+d+e+f+g)	$ TIV	150	0	0
Personal value of benefits ($/year)				
1. Comfort				
- no drafts	$ A	50	50	50
- high humidity	$ B	200	200	200
- summer cooling	$ C	100	100	100
- pleasant space (natural environment)	$ D	50	50	50
2. Quietness	$ E	80	60	60
3. Using renewable resources	$ F	30	0	0
4. Energy security	$ G	30	0	0
5. Energy cost savings	$ H	460(2)	240(3)	430(4)
6. Other?	$ I	0	0	0
Total Benefit Value: (A+B+C+D+E+F+G+H+I)	$ TBV	1000	700	890
Net Personal Value: ($/year) (TBV-TIV)	$ NPV	850	700	890
Simple Investment Payback: (years) (NIC/NPV)	SIP	4	5	6
Simple Return-On-Investment: (%) (NPV/NIC)	SROI	25	21	15

NOTES on Table 11.1:
1. This value was determined by deleting the costs associated with natural gas from TEC and TCR (see Chapter 3, Sections B and C).
2. From Table 3.1.
3. From Appendices C and D, Table 6.
4. Calculated for natural gas from the analysis in Appendix C, Table 6.

It can be assumed that with the increase in the number of low-energy houses, innovations in these heating systems will continue to be developed, especially if there is enthusiastic support from government agencies.

RECOMMENDATIONS

1. The designer of low-energy homes should be very concerned with the possibility of overheating in the summer and swing seasons (spring and autumn). Due care must be taken in the design to ensure adequate storage or ventilation of excess energy, and shading from unwanted summertime solar gains.

2. The calculations expressed in this chapter should be seriously addressed by any computer program that analyses residential energy performance. These calculations can assist in providing homeowners and the housing industry with the answers they need regarding energy supply options, and the benefits of energy conservation and solar energy.

Table 11.2 Contribution of ER-1's energy sources relative to the standard comparison house

	Energy utilized (GJ)	Fraction of total energy (%)	Value of energy in natural gas costs (1981)
Total energy required by the standard house for space heating	199	100	$750
Energy conserved by energy-saving measures	177	59	441
Total energy required by ER-1 for space heating	81	41	305
Total gain from domestic activity	27	14	102
Gross supplemental space heating	54	27	204
Utilized solar gain	34	17	128
Net required supplement	20	10	75

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Appendix A. HOUSE ELEVATIONS AND FLOOR LAYOUT

Figure A.1 North, East, West, and South Elevations

Figure A.2 Upper floor, Main floor and Basement/Crawl space layouts

Figure A.3 Cross-Section showing construction of ceiling, and above and below grade wall sections

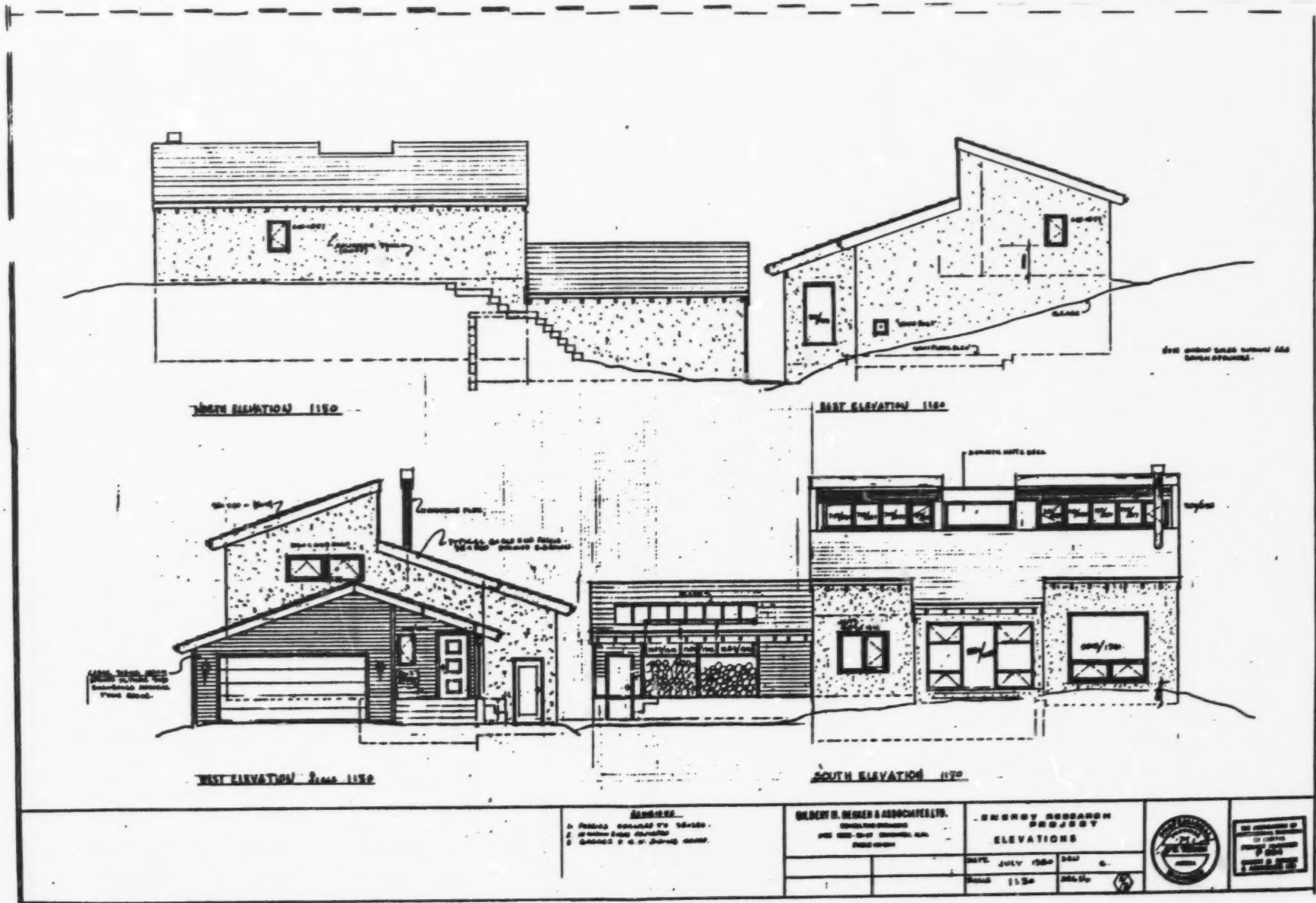

Figure A.1 North, East, West, and South Elevations

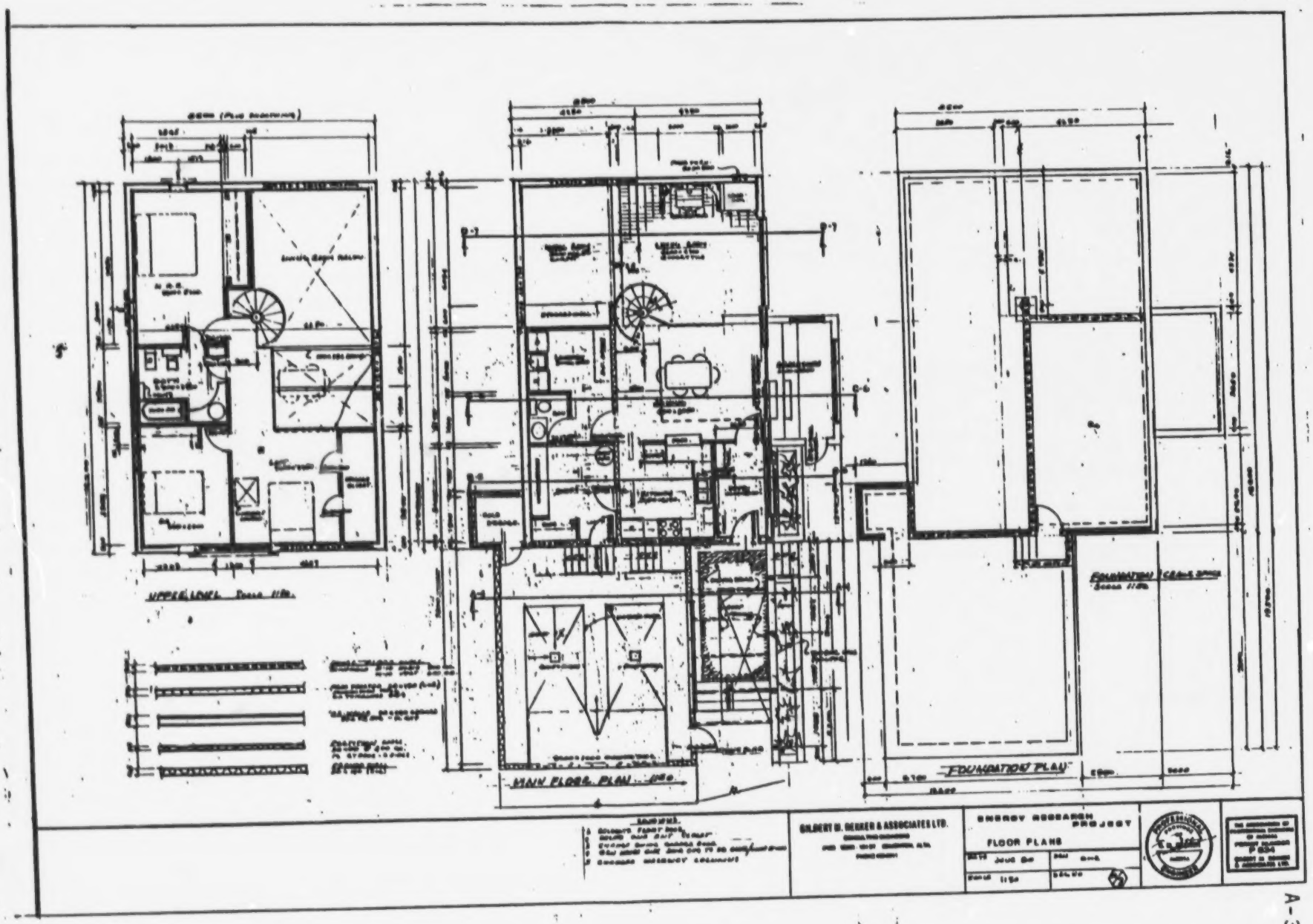

Figure A.2 Upper floor, Main floor and Basement/Crawl space layouts

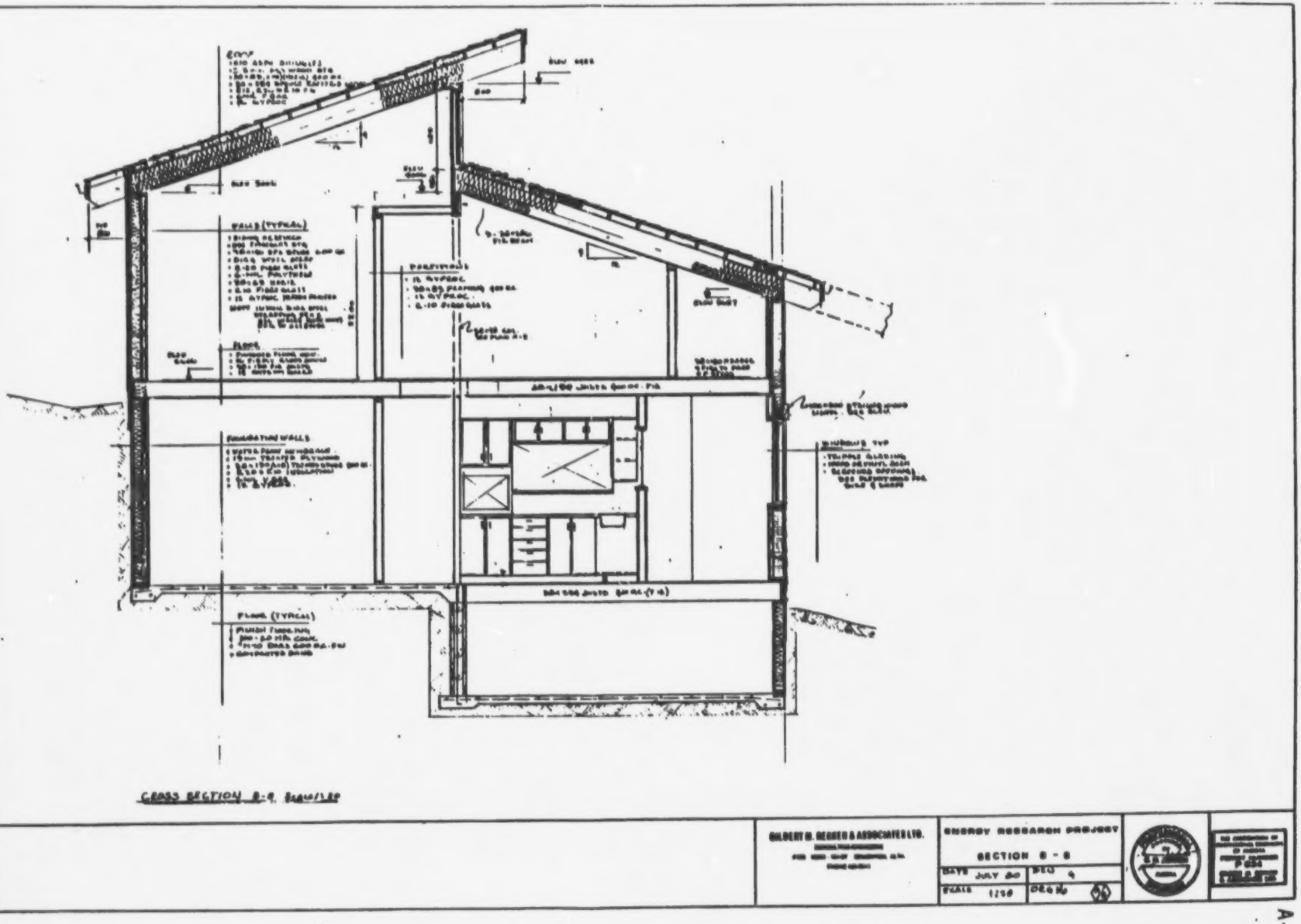

Figure A.3 Cross-Section showing construction of ceiling, and above and below grade wall sections

Appendix B. ENVELOPE COMPONENTS

The materials used in constructing the envelope systems of ER-1 are listed below. The list begins with the materials on the interior side.

1. Roof. Thermal resistance Rsi 7.7

- 15 mm drywall,
- 135 micrometre air/vapour barrier, well sealed with acoustic sealant,
- 2x10 rafters at 600 mm centres, 240 mm thick cavity filled with layered Rsi 3.5 and 2.1 pink glass fibre batt insulation,
- 2x4 purlins on edge at 400 mm centres, running perpendicularly to rafters, 89 mm thick cavity filled with Rsi 2.1 pink glass fibre batt insulation,
- 10 mm plywood sheathing,
- light brown 10 kg/m2 asphalt shingles.

2. Above Grade Walls. Thermal resistance Rsi 5.5

- 12 mm drywall
- 2x3 ribbons on edge at 600 mm centres, running horizontally, 64 mm thick cavity filled with Rsi 1.4 pink glass fibre batt insulation,
- 135 micrometre air/vapour barrier, well sealed with acoustic sealant,
- diagonal steel wind bracing
- 2x6 studs at 600 mm centres, running vertically, 140 mm thick cavity filled with Rsi 3.5 pink glass fibre batt insulation,
- rigid, high density glass fibre insulated sheathing, Rsi 0.8, manufactured with an exterior covering of TYVEK air barrier,
- cream coloured stucco finish.

3. Below Grade North Wall. Thermal resistance Rsi 5.5 + soil

- 12 mm drywall,
- 1x4 ribbons to allow easy installation of electrical wires, at 600 mm centres, 10 mm thick cavity lined with household aluminium foil to reduce radiation loss, Rsi 0.5 for single-sided reflective air space,
- 135 micrometre air/vapour barrier, well sealed with acoustic sealant,
- 2x8 preserved wood studs at 300 mm centres, running vertically, 190 mm thick cavity filled with Rsi 4.6 pink glass fibre batt insulation,

.....cont'd

3. Below Grade North Wall (continued)

- 15 mm preserved plywood,
- 500 micrometre water barrier,
- set into a hill 2600 mm below grade.

4. Living Room Floor. Thermal resistance Rsi 1.9 + soil

- low pile cream coloured carpet,
- 100 mm concrete,
- 50 mm high density expanded polystyrene rigid insulation,
- 135 micrometre vapour barrier,
- compacted soil,
- located 600 mm below grade.

5. Main Floor. Thermal resistance Rsi 0.1 + soil

- same construction as the Living Room Floor, but with no insulation,
- compacted soil,
- set into a hill 2600 mm below grade.

Appendix C. COMPUTER DESIGN ANALYSIS: ER-1, AS BUILT

Table 1. Environment data source

Radiation data: Stony Plain Upper Air Station
Climate data: Edmonton International Airport

Table 2. Design conditions

Outside design temperature	-37 C
Soil design temperature	5 C
Interior daytime temperature, start at 07 h	20 C
Interior nighttime temperature, start at 22 h	17 C
Daily average inside air temperature	18.9 C

Table 3. Activity profile

Electricity consumption in appliances & lights	250 $/year
Number of occupants	2
Domestic hot water consumption	180 l/day
Domestic hot water set temperature	60 C
Domestic water supply temperature (estimated annual average temperature from the solar water heater)	25 C
Domestic hot water heater tank insulation	1.50 m2·K/W

Table 4. Solar gain windows

	Area (m2)	Height (mm)	Glazing Layers	Overhang Projection (mm)	Gap (mm)
Clerestory	4.1	730	3	800	275
Main floor south	11.1	1400	3	0	0
Solar water heater	1.8	850	2	0	0

Table 5. Energy prices at Stony Plain, Alberta, 1981/82

Domestic electricity	12.13 $/GJ
ELECTRICITY for supplementary space heating	12.13 $/GJ
Supplementary space heater efficiency	100 %
ELECTRICITY for supplementary water heating	12.13 $/GJ
Supplementary water heater efficiency	100 %
Service charge for supplementary heating	0 $/month

Table 6. Component specifications

Component	Area (m2)	Rsi (m2·K/W)	ELECTRICITY heating cost ($)	(%)
Ceiling/roof	113.5	7.90	$24	10
Frame walls above grade	111.0	5.50	34	14
Greenhouse walls	19.8	4.20	8	3
House/garage wall	15.1	5.50	4	1
Foundation walls	44.0	6.00	10	4
Main floor slab	47.0	2.10	30	12
Living room floor slab	18.0	2.60	9	4
Basement floor slab	33.0	2.10	21	9
South windows	21.1	0.57	62	25
Non-south windows	5.0	0.57	15	6
Water heater window	2.0	0.35	10	4
Exterior doors	5.8	2.50	4	2
Ventilation volume, rate	540 m3,	0.10 /h	17	7
TIGHT vapour barrier,	FRESH AIR HEAT EXCHANGER USED			
Heater efficiency 100%,	heater wastage $ 0, 0 GJ			

Design heat loss rate: 6500 W

Annual ELECTRIC supplementary heating consumption -

space:	20 GJ, 245	$/year
water:	12 GJ, 144	$/year
Service charge:	0	$/year
Total heating bill:	389	$/year

Table 7. Monthly space heating energy value (in terms of ELECTRICITY energy cost)

Month	Total heat required	Appliance & people gain	Solar gains	Net heat supplement	House efficiency %
January	$146	$ 36	$ 49	$ 61	58
February	121	33	50	38	69
March	116	29	51	36	69
April	78	23	30	25	68
May	56	19	20	17	70
June	41	18	15	8	80
July	31	19	21	0	100
August	35	19	31	0	100
September	50	23	48	0	100
October	72	29	61	0	100
November	104	36	54	14	87
December	131	39	43	49	63
Year TOTAL	$981	$323	$473	$245	75%

Table 8. Solar energy contribution

Month	Total heat required (GJ)	Utilized solar (GJ)	Fraction of total supplied by solar (%)	Gross supplement required (GJ)	Fraction of supplement supplied by solar (%)
January	12.0	4.0	33	9.1	44
February	10.0	4.1	41	7.3	56
March	9.6	4.2	44	7.2	58
April	6.4	2.5	39	4.5	56
May	4.6	1.6	35	3.1	52
June	3.4	1.2	35	1.9	63
July	2.6	1.0	38	1.0	100
August	2.9	1.3	45	1.3	100
September	4.1	2.2	54	2.2	100
October	5.9	3.5	59	3.5	100
November	8.6	4.5	52	5.6	80
December	10.8	3.5	32	7.6	46
Year TOTAL	80.8	33.6	42	54.2	62

Table 9. Contribution of the different energy sources to the heating of ER-1

	Energy utilized (GJ)	Fraction of total energy (%)	Value of energy in electricity costs (1981)
Total energy required by ER-1 for space heating	81	100	$981
Total gain from domestic activity	27	33	323
Gross supplemental space heating	54	67	658
Utilized solar gain	34	42	412
Net required supplement	20	25	245

See also Appendix E: "NOTES ON THE PERFORMANCE ANALYSES"

Appendix D. COMPUTER DESIGN ANALYSIS: STANDARD COMPARISON HOUSE

Table 1. Environment data

Radiation data:	Stony Plain Upper Air Station
Climate data:	Edmonton International Airport

Table 2. Design conditions

Outside design temperature	-37 C
Soil design temperature	5 C
Interior daytime temperature, start at 07 h	21 C
Interior nighttime temperature, start at 22 h	18 C
Daily average inside air temperature	19.9 C

Table 3. Activity profile

Electricity consumption in appliances & lights	250 $/year
Number of occupants	2
Domestic hot water consumption	180 l/day
Domestic hot water set temperature	60 C
Domestic water supply temperature (estimated annual average temperature from the solar water heater)	25 C
Domestic hot water heater tank insulation	0.50 m2·K/W

Table 4. Solar gain windows

	Area (m2)	Height (mm)	Glazing Layers	Overhang Projection (mm)	Gap (mm)
Clerestory	4.1	730	2	800	275
Main floor south	9.0	1400	2	0	0
Solar water heater	1.8	850	2	0	0

Table 5. Energy prices at Stony Plain, 1981/82

Domestic electricity	12.13 $/GJ
NATURAL GAS for supplementary space heating	2.45 $/GJ
Supplementary space heater efficiency	65 %
Effective cost due to heater inefficiency	3.77 $/GJ
NATURAL GAS for supplementary water heating	2.45 $/GJ
Supplementary water heater efficiency	63 %
Effective cost due to heater inefficiency	3.89 $/GJ
Service charge	6.50 $/month

Table 6. Component specifications

Component	Area (m2)	Rsi (m2·K/W)	NATURAL GAS heating cost ($)	(%)
Ceiling/roof	113.5	6.00	$27	6
Frame walls above grade	111.0	2.10	75	15
Greenhouse walls	19.8	2.10	13	3
House/garage wall	15.1	2.10	8	2
Foundation walls	44.0	0.90	56	12
Main floor slab	47.0	2.10	26	5
Living room floor slab	18.0	2.10	10	2
Basement floor slab	33.0	2.10	18	4
South windows	18.5	0.35	75	15
Non-south windows	7.6	0.35	31	6
Water heater window	2.0	0.35	8	2
Exterior doors	5.8	1.00	8	2
Ventilation volume, rate	540 m3,	0.50 /h	131	27
STANDARD vapour barrier,	NO FRESH AIR HEAT EXCHANGER USED			
Heater efficiency 65%,	heater wastage $171,		69.8 GJ	

Design heat loss rate: 16300 W

Annual NATURAL GAS supplementary heating consumption -

space:	128 GJ,	484 $/year
water:	16 GJ,	63 $/year
Service charge:		78 $/year
Total heating bill:		625 $/year

Table 7. Monthly space heating energy value (in terms of NATURAL GAS energy cost)

Month	Total heat required	Appliance & people gain	Solar gains	Net heat supplement	House efficiency %
January	$112	$ 13	$ 15	$ 84	25
February	92	12	16	64	30
March	89	10	16	63	29
April	59	9	10	40	32
May	42	7	7	28	33
June	31	7	5	19	39
July	23	7	7	9	61
August	27	7	10	10	63
September	39	9	15	15	62
October	55	10	19	26	53
November	80	12	17	51	36
December	101	13	13	75	26
Year TOTAL	$750	$116	$150	$484	35%

Table 8. Solar energy contribution

Month	Total heat required (GJ)	Utilized solar (GJ)	Fraction of total supplied by solar (%)	Gross supplement required (GJ)	Fraction of supplement supplied by solar (%)
January	29.7	4.0	13	26.3	15
February	24.4	4.2	17	21.2	20
March	23.6	4.2	18	21.0	20
April	15.7	2.7	17	13.3	20
May	11.1	1.9	17	9.3	20
June	8.2	1.3	16	6.4	20
July	6.1	1.9	31	4.2	45
August	7.2	2.7	38	5.3	45
September	10.3	4.0	39	8.0	50
October	14.6	5.0	34	11.9	42
November	21.2	4.5	21	18.0	25
December	26.8	3.4	13	23.3	15
Year TOTAL	199.0	39.8	20	168.2	24

Table 9. Contribution of the different energy sources to the heating of ER-1

	Energy utilized (GJ)	Fraction of total energy (%)	Value of energy in natural gas costs (1981)
Total energy required for space heating	199	100	$750
Total gain from domestic activity	31	16	116
Gross supplemental space heating	168	84	634
Utilized solar gain	40	20	150
Net required supplement	128	64	484

See also Appendix E: "NOTES ON THE PERFORMANCE ANALYSES"

Appendix E. NOTES ON THE PERFORMANCE ANALYSES

The following notes comment on the performance analyses contained in Appendices C and D.

1. To include furnace heating efficiency in calculations, an "effective energy cost" should be calculated. This cost equals the purchased price of the fuel divided by the furnace heating efficiency.

In Appendix D, the purchased cost of natural gas is $2.45/GJ, but for space heating, since 35% is assumed as being wasted, the effective cost is 2.45 / 0.65, or $3.77/GJ. It is this effective cost that should be used when comparing energy supply options.

2. The insulation standards of the comparison house conformed to the 1982 CMHC guidelines. This house was assumed to have good solar orientation. Much of the existing house stock performs substantially poorer that this due to low insulation and air-tightness levels, and poor solar access.

3. The estimates of daily and monthly patterns of electricity consumption, house temperature setting, and water consumption effect house energy performance analyses. These analyses can be further refined by a more complete understanding of the patterns.

4. The analyses do not consider shading from landscaping. In ER-1, the solar gain levels would be somewhat lower than shown in Appendix C.

5. The performance estimates are given for an average year. Variations in the annual temperature cycles, solar availability and lifestyle typically change the actual performance by up to 25% from the estimate.

6. It is seen in Table 7 in Appendix C that the total solar energy available to ER-1 is not completely utilized. Some of the energy is dumped in the summer months when all the heating requirements have been met.

7. When comparing Table 9 in the two appendices, it appears that the gain from domestic activities (appliances and people) is larger in the standard comparison house than ER-1. This difference is due to the assumption that the natural gas water heater in the comparison house is not as well insulated as the electric water heater in ER-1 (shown in Table 3). The result is that more heat from the water heater supplies the house heating requirments.

POOR

QUALITY

ORIGINAL